THE INSULATION OF ELECTRIC MACHINES

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PREFACE

THE preparation of this treatise on the Insulation of Electric Machines has been undertaken to render available to engineers some portion of the results of twenty years of practical work with insulating materials, and of careful study of their insulating properties. Probably no other properties of any materials employed by engineers are so indefinite as these, and it is essential for anyone, on taking up the subject, to disabuse his mind of the idea that a high degree of accuracy is at the present time attainable.

The insulation of cables, which is excluded from this volume, is the only case in which the use of insulating materials has been reduced to some degree of exactness. The experience gained in cable manufacture might often be employed with advantage in the insulation of electric machines.

That we still have a great deal to learn on the subject of insulating materials, has been referred to by O'Gorman in his paper on the "Insulation of Cables" (*Proc. Inst. Elec. Engrs.*, vol. xxx. p. 608), in which he states:—

"We scarcely realise how unlimited and how unexplored are those fields of research. Suppose that by dint of mixing gums, resins, oils, powders and solvents, we should get a perfect dielectric, waterproof for one hundred years, flexible and extensible, so volt-resisting that the thinnest film suffices, with a specific capacity almost as low as that of air, yet adjustable to a high value; sufficiently firm not to decentralise, yet fluid enough, when heated by an arc, to close in and seal up a fault. Suppose, besides all this, we can make it at 5d. per lb. applied, what will be the reward? Far more than the value of the three-wire patents or the Dunlop tyre, plus the benediction of all electricians."

One is naturally averse to mentioning the names of manufacturing firms in a technical work on the properties of materials. In

the present instance, however, it has been practically impossible to avoid some references, and it is hoped that no injustice will result to those firms whose products may be equal or superior in quality to those of the firms mentioned. In other cases, we have adversely criticised various insulating materials which our experience has led us to regard as defective, or unsuitable for certain purposes. Manufacturers' publications are nowadays amongst the best sources of technical information, and we have frequently found that it is in the interests of a thorough understanding of the subject, to quote at length from the publications of rival manufacturers. The reader will, however, hardly need to be cautioned to keep distinctly in mind the tendency of manufacturers to be partial to their own products. Several manufacturers have generously assisted us by furnishing information and samples.

We wish to express our appreciation of the cordially granted permission for us to make copious extracts from the work of the respective authors of the very valuable papers that have appeared during the last ten years on this subject. When making such duly accredited extracts, we give our readers the benefit of each author's carefully considered wording, just as we deal with our own work in our own words. Such papers have been few in number and limited in scope, no comprehensive treatise having hitherto appeared.

The metric system has been employed throughout the treatise.

Amongst the authors to whom we should like to express our indebtedness may be mentioned:—Dr C. Baur, Mr C. E. Farrington, Dr R. A. Fessenden, Dr R. T. Glazebrook, Mr Mervyn O'Gorman, Mr H. F. Parshall, Dr F. A. C. Perrine, Mr C. E. Skinner, Dr C. P. Steinmetz, and Mr P. H. Thomas.

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THE INSULATION OF ELECTRIC MACHINES

CHAPTER I

INTRODUCTORY CONSIDERATIONS

FIVE years ago, one of the ablest authorities on the subject of insulation made the following statement:[1]

"I have no hesitation in saying that there are not more than one or two companies in the United States whose insulations are worth more than so much bare cotton cloth after two years' service." The remark applied more especially to the varnishes with which tapes, cloths, and papers were impregnated. Progress in the manufacture of electrical machinery, especially with relation to the insulating methods employed, has during recent years been rapid; nevertheless, there still appears to be much more groping in the dark in this matter than should longer be necessary,[2] and it is the purpose of the writers of this treatise, to set forth in serviceable form the information and experience which they have

[1] *Proc. Amer. Inst. Elec. Engrs.*, vol. xv. p. 156.

[2] "The best excuse for a discourse on the defective insulation which is found in modern dynamo and motor construction is the statement that it is the greatest obstacle to electrical development at the present time. It is a fact beyond controversy that the electric motor is not being used as much as it would be if it were a more perfect machine.

"From one end of this country to the other you can go into the street railway field, and find apparatus which has gone to the scrap heap chiefly because it has been insulated with defective insulation. Within a year, one of the largest generators in the world has had its armature twice re-wound because it was insulated with defective insulation, and on the third trial its builders repaired it with the same stuff which first short-circuited it. The money loss in that instance is already close to

accumulated on this subject. In the case of one of them, this experience has been very thorough and of a decidedly practical character, having been gained during the last twenty years in winding and insulating, and in designing and supervising the

$10,000, with more to follow. There is not a central station manager in the United States, who has tried to sell power, who has not come into contact with a manufacturer or a machine-shop superintendent who told him he would not put in a motor unless the central station man would guarantee against his shut-down losses and against repairs. Printers have discarded electric motors for gas engines, because they say the gas engines have a reliability which motors have not.

"Every defective electric motor is an argument for the sale of an engine in its place, and it is only so because the motor manufacturers have neglected, in their rush to keep up with commercial progress, to give to their insulation the same care and thought which the engine builders have given to their construction. The same process of elimination which keeps poor metal out of piston rods will keep poor insulation out of armature coils. But at present manufacturers will not seek such improvement until consulting and operating engineers insist upon it."—C. E. Farrington, "Defective Machine Insulation." A paper read before the Franklin Inst. at Philadelphia on March 12, 1903.

"Up to now, the electrical engineer has in most cases been left to himself to find the best insulating material for his particular purpose. All he could do was to pick out the most promising ones among those offered to him by the trade. But he is far from having the ideal materials for the different types of insulation, especially for high-tension work, which is greatly handicapped by the lack of suitable insulating materials."—Dr Max von Recklinghausen, American Electro-Chemical Society, April 16, 1903.

"I had recently sent me by a large manufacturer of street railway motors, a piece of insulating material, for which he claimed very considerable virtues; which had been the best insulation he had used so far, and which he had only abandoned on account of its very high price. On my testing a sample taken from a motor about a year old, I found that it had been originally a very good quality of canvas, covered, above all things in the world, with rubber. Of course, the rubber had totally gone to pieces, and was in the form of a black non-cohesive powder. Its insulating properties proved so poor, that on placing a drop of water on one side of it, in thirty seconds it came through on the other side.

"The trouble is that the insulating department of a company is generally put in charge of some young man of very little practical experience. He is generally a good and able man; makes a lot of experiments which have been made over and over again by others, but not published; thinks he has found some good things; and after a year or so, when he begins to see how the machines brought in for repair look, and is really beginning to learn something, is promoted to a better position, and the next man goes through the same thing. To again take an example, one of the most common things for the beginner to do is to make up a gum varnish as an insulator. I know

winding and insulating processes in the largest electric factories in England, America and Germany.

In electrical machinery, the question of insulation is one of vital importance. We have ample evidence that present practice in this department generally reflects haphazard and individual opinions, rather than a thorough practical study of the requirements in each case.[1]

personally at least ten cases of this. Now, old hands know that a gum varnish is no good; that it cracks within a year, that it splits in cold weather, that it never makes a good joint when used in paper or cloth, and that its only virtue is that it looks pretty for a time. Yet I suppose that there are at the present time at least a dozen companies using varnishes for insulation, at from \$1·50 to \$4·00 per gallon, when pure borated oil, superior in every respect, can be got for about 30 cents per gallon."—Fessenden, "Insulation and Conduction," *Proc. Amer. Inst. Elec. Engrs.*, vol. xv., 1898, p. 156.

"We asked our electrical friends for full details on the work an insulating varnish had to do. The answer, signed by one of the best known of the large construction concerns of a dozen years ago, is in my possession to-day, and reads:—'An insulating varnish must contain as little water as possible and dry quickly. We cannot give you further details, but if you will make the varnish as above stated, we will make the tests to see whether it has any insulating properties.'

"If such an answer had been rendered on any other point concerning mechanical or electrical engineering, it would have been considered a glaring admission of ignorance, and no large electric company would have tolerated such ignorance after it had once exposed itself."—C. E. Farrington, "Defective Machine Insulation." A paper read before the Franklin Institute of Philadelphia on March 12, 1903.

"In the early development of electric lighting and traction industry, large quantities of insulating paint were deemed necessary, and a mixture of rubber and asphaltum in carbon bi-sulphide and naphtha solution was marketed in enormous quantities by clever advertising. The chief quality of this mixture was its sickening stench, as by reason of its chemical defects it was subject to changes in its character which made it utterly unreliable. When electricians sought a practical substitute they were confronted with the old formula of asphaltum, linseed oil, and turpentine, a material whose durability has always been scoffed at by honest paint-makers. There was nothing else."—From a publication by the Massachusetts Chemical Co.

[1] "It is a fact that electrical engineers have neglected to use the methods of applied chemistry in this most important item of their work. They have cheerfully gone on and on, jauntily ignoring well-known chemical laws, and trusting to the cleverness of their sales departments to shift to buyers the responsibility for losses and annoyances, which might be wholly avoided were conscientious study made of the problem." C. E. Farrington, Franklin Institute, March 12, 1903.

Some of the most important requisites for satisfactory insulating materials are[1]—

I. High insulating quality.
II. Toughness to withstand mechanical strains.
III. Ability to withstand vibration.
IV. Flexibility and freedom from brittleness.
V. Longevity.
VI. Ability to exclude moisture.
VII. Ability to withstand heat.
VIII. Ability to withstand the action of acids.[2]
IX. Adaptability to use in such forms and ways as to permit of a high "space factor."

[1] Dr Max von Recklinghausen (paper read before the American Electro-Chemical Society, April 16, 1903) has classified the properties under which the different insulating materials have to be considered as follows :—

"I. Electrical properties :—
A. Insulation resistance or conductivity, expressed in ohms per cubic centimetre.
B. Disruptive or dielectric strength, measured by the high potential voltage necessary to puncture the material.
C. Dielectric constant or specific inductive capacity, measured by the capacity in microfarads of a condenser having the particular material as dielectric separating the metal plates. (This property is less important than the ones mentioned under A and B.)

"II. Mechanical properties :—
A. Strength and workability. (For solids.)
B. Flexibility and workability. (For semi-solids.)
C. Viscosity. (For liquids.)

"III. Chemical properties :—
A. Combustibility.
B. Property of resisting influence of moisture (hygroscopic quality), air, oil, acids, etc.

"Desirable qualities are, mainly, good insulation resistance, high disruptive strength, fair mechanical properties, especially workability.

"Undesirable qualities are, mainly, combustibility and changes in the electrical and mechanical properties with rise of temperature or with age, and, of course, *high price.*"

[2] "At the very outset newly wound armatures show strong electrolytic action even when they have not been varnished. This is caused by the acids and moisture contained in the cotton covering of the wire. This action impregnates the cotton covering of the wire with salts of copper and destroys its insulation. By baking the armature in an oven this electrolytic action is arrested, unless more moisture be absorbed from the atmosphere. This chemical action is much more apparent and more disastrous when it is set

As regards an expression for the insulating qualities, a great deal of indefiniteness exists. It was, in the earlier days, very general to express the insulation resistance in megohms, and to regard that substance as the best insulator which gave by measurement the highest ohmic insulation resistance. But while a substance may have a high ohmic insulation resistance, it may nevertheless often, one might say *generally*, be characterised by having a lower disruptive strength than a substance of far lower ohmic insulation resistance. There has been, and still is, considerable indefiniteness[1] as to what is meant by a substance's "insulation." The writers generally mean its "disruptive strength."

up in an armature which has been treated with varnishes containing shellac, copal, kauri or Zanzibar gum, or linseed oil, for the simple reason that these materials are almost wholly composed of various ill-united resin and gummy acids. The union of these acids is easily broken down by electrolytic action and by oxidation, and when set free they will attack copper wire, causing an enormous drop of insulation resistance, whence also the green discoloration so frequently found in armature and field windings."—From a publication of the Massachusetts Chemical Co.

[1] "A thing insulates because it is possessed of two distinct properties: first, the ability to stand the mechanical and electrical stresses due to the voltages used; secondly, because it is such a poor conductor that but a negligibly small current can flow through it and leak away. In other words, it will neither allow the current to break through it nor steal through it. The first property is called by Maxwell the 'dielectric strength' of the insulator, the other property is called the ohmic resistance. The two together form its insulating power."—R. A. Fessenden, "Insulation and Conduction," *Proc. Am. Inst. Elec. Engrs.*, vol. xv. p. 119, 1898.

"Electrical insulation, or the prevention of electrical motion, is analogous to the mechanical operation of fixing bodies by ropes and beams to prevent their motion; and, considering the materials which are used as insulators, it is very much as if we had only molasses or pitch to make our ropes and beams of. If we had only pitch to make ropes of, there would be two very distinct items of strength. If you wish to subject a pitch rope to a given stress, you would need to consider, first, at what rate the rope would lengthen. This rate of lengthening multiplied by the stretching force would give the rate at which energy would be continuously dissipated in the stretched rope. Second, whether the given stress would be sufficient to snap the rope in two.

"We have thus a complete mechanical analogy of the two items of strength of insulators. In one case the insulator gives way continuously under the electrical stress, and in the other case it breaks to pieces."—W. S. Franklin, *Proc. Am. Inst. Elec. Engrs.*, vol. xv., 1898, p. 152.

"These three totally different kinds of resistance have, I fear, been rather mixed up in the discussion this evening, and it is very important to dis-

What is wanted in electrical machinery is high disruptive strength, that is, great power of withstanding high voltages without sustaining injury or initiating deterioration, and modern specifications and tests should aim at ensuring that a piece of completed apparatus shall be able to withstand under test the application of a voltage several times in excess of the highest voltage to which it will ever be subjected in normal operation. There is here great need for precision of statement as to whether the test shall be applied hot or cold, for a long time or only for an instant, from any sort of a machine, and over any sort of a circuit and transforming apparatus, or from an alternating current circuit with specified wave shape and periodicity, and from apparatus of prescribed minimum capacity.

It should be specified whether the voltage shall be continuous or alternating;[1] if alternating, of what periodicity and wave shape,

tinguish between them. For example, air has a very high specific resistance but not much dielectric strength; glass has a large dielectric strength, but not nearly as high a specific resistance as air; and paraffin wax has a larger surface insulation than glass, but not as high a specific resistance as good glass."—Ayrton, *Proc. Am. Inst. Elec. Engrs.*, vol. xxi. p. 281.

"It cannot be emphatically enough stated that the disruptive strength rather than the megohm resistance is generally the true measure of the usefulness of an insulating material. The apparent resistance in megohms is chiefly dependent upon the character of the surface available for leakage, and this varies from time to time according to conditions of dampness, etc. On the other hand, tests of the disruptive strength permit of forming very reliable conclusions with respect to the usefulness of a given insulating material.—Holitscher, *E.T.Z.*, 1902, p. 170.

[1] The Compagnie de l'Industrie Électrique et Mécanique of Geneva recently made some tests on the disruptive voltages with continuous-current and alternating-current voltages, and found for various materials a much greater disruptive strength in favour of the former than corresponds with the ratio of the maximum to the R.M.S. (root-mean-square, or effective) values of the alternating current. In an article by Steens, entitled "Direct-Current Transmission at 70,000 Volts," published on p. 603 of the *Electrical Review* for Oct. 14, 1904, some of these tests are described as follows:—

"A number of insulating substances were tested for perforation. First a sheet was tested with alternating current, with the following results:—

	Time of Electrification.	Pressure.	Results.
1st test	90 secs.	9,000 volts.	...
	30 " later	11,000 "	Spark passed.
2nd test	120 "	9,000 "	Strong brushes.
	15 " later	9,000 "	Spark passed.

and whether the voltage shall be the *effective* voltage, *i.e.* the root-mean-square (or R.M.S.) value, or the maximum voltage.

It is the surprising absence of details on these various points in

"The same sheet subjected to direct current gave the following results:—

120 secs.	10,000 volts.	...
120 „	15,000 „	...
120 „	18,000 „	...
120 „	20,000 „	...
240 „	25,000 „	Spark passed.

"Thus this specimen, twice pierced by alternating current after, on the average, two minutes' application of 10,000 volts a.c., was able to withstand during twelve minutes a mean pressure of more than 15,000 volts, and only gave way after the application of 25,000 volts d.c. for four minutes. Afterwards a sheet of white marble 20 mm. thick was tried. The specimen was perforated after 75 seconds' application of 20,000 volts a.c. A second test led to perforation after two minutes with 15,000 volts a.c.

"Perforation with direct current was only accomplished after fifteen minutes' application, at pressures from 10,000 to 45,000 volts, the pressure being raised 5000 volts once every two minutes. Already weakened by the preceding experiment with a.c., the specimen showed light brushes from 10,000 volts, increasing up to 45,000 volts, a critical point. This test shows very clearly, like the former, how much better the insulating materials resist d.c. than a.c. pressures. All the substances afterwards tested gave analogous results. At perforation, the d.c. pressures required are always more than double the a.c. pressures, and when capacity plays an important part the difference is still more noticeable."

"Glass is very difficult to pierce with d.c. Ordinary white glass of 0·3 mm. resists 25,000 volts very well, and is only pierced when one provokes an oscillating discharge by means of a condenser; a sheet of window glass resists 60,000 volts d.c., and probably more still."

No heating of the insulator was observed in the continuous-current tests, and to this is probably due in large measure the greater disruptive strength as compared with that observed with alternating current. It would be of interest to have added tests with alternating currents of widely different periodicities.

The article continues:—

"The direct current is reproached with the ease with which it electrolyses certain insulators, and gradually weakens them by forming a metallic bridge, which eventually completely penetrates and destroys them. But practice long ago showed that this cannot take place unless there is moisture in the insulating material. Now, it is not necessary to use such substances, for one has at hand materials of the best quality, such as glass, porcelain, mica, etc., which enable one to entirely exclude the possibility of electrolysis. Thanks to the heat disengaged within them, dynamos, motors, etc., rapidly part with the slight moisture absorbed whilst at rest or in store, a fact which explains why electrolysis, as is well known, is not experienced in such apparatus if they are kept reasonably dry."

the available reports of tests which tempt one to throw them all aside as worthless, and to start afresh. Nevertheless, the results of many in other respects elaborate and painstaking tests are available, and we shall preface our remarks by a presentation of the mean results of a few of the most useful among these tests. The

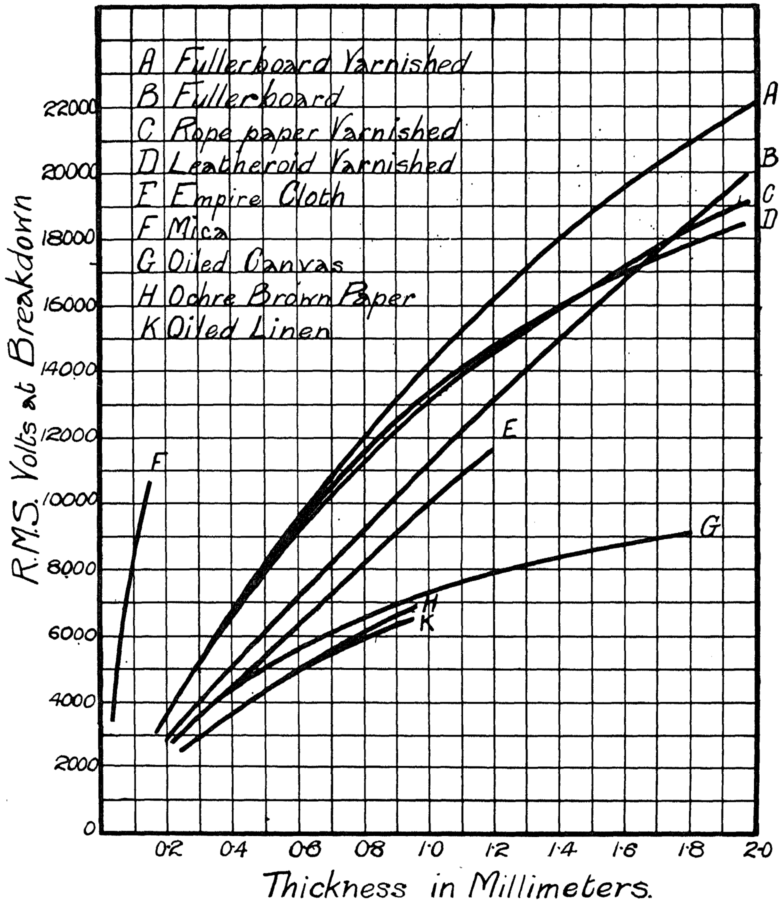


FIG. 1.—Curves of Disruptive Strength of Various Insulating Materials.

difficulty of specifying the degree of absence of moisture in samples is frequently a cause of lack of uniformity in results, and there is only too often ample evidence that no suitable precautions to ensure the absence of more than the necessary minimum of moisture preceded the tests. Nevertheless, the results set forth in the groups of curves of fig. 1 serve to at least fix ideas as to

magnitudes. From these curves we see that *samples* built up to a thickness of 1 mm. suffice to withstand 5000 R.M.S. volts for a great variety of materials, and that for most of these materials 1 mm. thickness suffices at normal temperature to withstand 7000 R.M.S. volts, and more.

Nevertheless, it is in practice a matter requiring the greatest attention to detail, as well as care in the selection of materials, to build an armature with only 1 mm. total thickness of insulation from the copper conductors to the iron core, which will stand—say, for one minute at 20° Cent.—the application at, say, 50 cycles[1] of 5000 R.M.S. volts from copper to iron. Few manufacturers are able to adopt so high as the half of this value as a standard test for completed apparatus built with this insulation allowance. Unless one is prepared to devote to this feature of armature construction much more attention and expense than is customary, 1 mm. thickness is too small an allowance for ensuring compliance with so rigid a test.

Mere thickness, however, is of but little avail. Thus if, after much careful development, the end is attained of standardising a line of machines with but 1 mm. thickness of insulation, capable of withstanding in 95 per cent. of the machines going to test an initial break-down test of 5000 R.M.S. volts, it would not be at once practicable, without further development, to standardise a double thickness of this same insulation for apparatus requiring to withstand a 10,000 volt test. The circumstance that for many materials a doubled thickness will withstand much less than twice the voltage relates to a property of insulation which as yet is by no means understood.[2] But it may be illustrated by the curves

[1] The periodicity is generally of but little influence when the test is of but one minute duration. But for long periods of application of the testing voltage, the heat developed in the insulation will in some cases also be dependent upon the periodicity employed. The influence of the periodicity is a troublesome question. Skinner has found a very considerable variation in the dielectric loss with varying frequency. This is discussed in Chapter II.

[2] "A test for disruptive strength on small thicknesses proves nothing about a large thickness of the same material, because a diminishing dielectric strength with increasing thickness is apparently inherent in most insulators, unless we allow that the experimenters whose results are available have made errors of remarkable similarity. I think Professor Perry would ascribe part of the apparent extra strength of small thicknesses to the preponderance

of figs. 75, 77, 78 and 82, in which as abscissæ are plotted the number of layers of certain materials and as ordinates are plotted the disruptive voltages per layer. Taking the case of untreated presspahn (fig. 75), it will be observed that one layer withstands on the average 2700 volts, two layers withstand but 2400 volts per layer, three stand 2250 volts per layer, four 2100 volts per layer, etc., the strength *per layer* rapidly decreasing. This is the more important since by testing several layers one would expect that the weak portions of one layer would be offset by the good portions of other layers, and that the *average* result *per layer* would thus be better the greater the number of layers.[1] This consideration undoubtedly comes in, and hence the phenomenon in virtue of which the strength per layer in the case of most materials decreases with an increasing number of layers must be even more marked than is indicated by the curves of figs. 75, 77, 78 and 82.

Different materials vary greatly in respect to this phenomenon, and it is a matter not to be overlooked in the choice of materials and treatments. Thus so-called "express-paper" (see fig. 79), and also "empire-cloth"[2] (see fig. 81), have nearly double as great

of skin-resistance when the total resistance is small. The weakness of the larger thicknesses might also be partly ascribed to the fact that when the electrodes are no longer very large compared to the spark gap, the stress lines will no longer be uniform, and the potential gradient will at some part of the insulation be greater than is given by the total voltage divided by the total distance between electrodes. There is also the extra likelihood of impurities."—O'Gorman, "Insulation on Cables," *Proc. Inst. Elec. Engrs.*, vol. xxx., 1901, p. 620.

[1] This is occasionally the case; thus in Fessenden's paper on "Insulation and Conduction" (*Proc. Am. Inst. Elec. Engrs.*, vol. xv. p. 144) is found the following paragraph:—

"A condenser so made, if perfectly pure cellulose is used (perfectly pure paper is used in practice), and with pure paraffin, will stand 250 volts per thousandth of an inch when the dielectric is less than ·01 inch, *and at a higher rate* for greater thicknesses when the effect of small defects in one sheet of paper is not so serious."

[2] "'Empire cloth' and 'express paper,' being flexible, are capable of being tightly compressed together so as to nearly exclude the air between layers. This film of air produces irregularities in the rate of fall of the potential through the dielectric, and the more completely this is excluded, the greater uniformity there will be in the results."—Harold D. Symons. (Paper read before the Students' Section of the Inst. Elec. Engrs., April 27, 1904.)

strength with two layers as with one, nearly triple with three, etc. But it does not suffice that the untreated material shall have this good property. In modern methods this material is often merely a sort of skeleton fabric, providing the framework for holding the film of insulating material such as oil or varnish. The skeleton framework must be extremely smooth and even, since projections from the surface—such as fuzz, threads, fibre or dust—break up the uniformity of the film's thickness. Hence cloth should be singed and ironed before the film of oil or varnish is applied.

In fig. 73 are plotted the results of tests of presspahn and horn fibre, boiled in linseed oil. In these cases a double number of layers does not stand nearly doubled voltage, although, as compared with the untreated materials, a great improvement in the actual disruptive strength has occurred. It is the more important that the extent of this effect of increasing thickness should be known, since the general and necessary practice of employing a considerably less specific thickness (*i.e.* thickness per volt) for higher voltage machines would lead to the reverse conclusion. On page 4 of vol. i. of *Traction and Transmission* Mr Parshall states:—"In armatures an approximate rule is that the insulation for a 500-volt armature should be approximately 0·05 inches (1·27 mm.) in thickness, the thickness for other voltages increasing approximately as the square root of the voltage." From this rule he derives the following table:—

TABLE I.—THICKNESS OF SLOT INSULATION FOR VARIOUS VOLTAGES.

Normal Voltage of Armature.	Thickness of Slot Insulation, millimetres.	Volts per mm. Thickness of Slot Insulation.
500 volts.	1·27	394
1,000 „	1·80	555
2,000 „	2·54	785
4,000 „	3·60	1,110
10,000 „	5·70	1,760

These insulation allowances would, however, not offer by any means the same factor of safety, for whereas in the case of 500-volt armatures it is common practice to require high tension tests

with a R.M.S. alternating current of from 5 to 8 times the rated voltage of the armature, 10,000-volt armatures are often passed after testing with but 1·5 to 2·0 times[1] the normal voltage.

Better material is employed in the slot insulation in the case of 10,000-volt armatures, and greater care is used at every step of the work. Were the same material and the same care used as with the 500-volt armatures, and were the puncturing voltage per mm. independent of the thickness, then a factor of safety one-third as great would, for the 10,000-volt armatures, require a slot thickness of

$$\frac{10,000}{500} \times \frac{1}{3} \times 1{\cdot}27 = 8{\cdot}5 \text{ mm.}$$

Hence, from Mr Parshall's figure of 5·7 mm. thickness, as suitable for 10,000-volt armatures, one could, on these assumptions, make the rough estimate that 50 per cent. $\left(\frac{8{\cdot}5 \times 1{\cdot}00}{5{\cdot}7} = 1{\cdot}50\right)$ represents the increased care exercised in choice and treatment of insulating materials for 10,000-volt armatures as compared with 500-volt armatures, and this would appear to generally be the case.

The writers have very good reason to believe that even the most progressive manufacturing firms are still comparatively uninformed in these matters. Probably nothing short of the most laborious, exhaustive and painstaking investigations[2] on a large number of

[1] Some firms take as the standard for high voltage induction motors an insulation test at a voltage 5 per cent. in excess of double the rated voltage of the motor; but such a test is in general not sufficiently severe to ensure freedom from break-downs in subsequent operation.

[2] "The materials must be tested under all the conditions occurring in practice; when cold and dry and also at as high as 100° Cent., a temperature frequently occurring in electrical machinery. They must also be tested when exposed to moisture. Tests between pointed electrodes should not be made, as the results are only of local significance. Circular plates should be used for electrodes, and they should have a surface of 10 sq. mm. Larger electrodes would only afford needless opportunity for leakage from the edges.

"Conclusions should only be drawn from tests on a large number of samples; and while the lowest values obtained are indications of the maximum strength on which one can rely, the variations amongst the individual results are a criterion of the uniformity of the material."—Holitscher, *E.T.Z.*, 1902, p. 170.

"The tests were usually made by placing the material between metal plates, which were connected to the terminals of a high potential transformer. The

materials, when raw and also when treated with various varnishes and subjected to various processes, can put the matter on a more satisfactory basis. Moreover, the tests should be made on a considerable range of thicknesses and numbers of layers, and at different temperatures. Ageing should not be overlooked, nor the hygroscopic and other properties of the materials and their impregnations.

Experience has shown that the size of the electrodes between which the materials are tested should always remain constant in order to obtain consistent results, and the mechanical pressure applied should also be the same in all comparative tests.

A device sketched in fig. 2 affords a simple means for making such tests.

The terminal discs have automatically adjustable surfaces, as the shanks fit loosely in tubes, and if necessary they may be replaced by other sized electrodes should occasion require; but discs of 25 mm. diameter, and with the edges well rounded, so that the bearing surfaces are of about 15 mm. diameter, answer the purpose for almost all comparative tests required in practice. The mechanical pressure may be adjusted by regulating the tension of the spring.

Every ultimate result should preferably be derived from an average of several samples,[1] because of the extreme variableness

plates employed for this purpose should always have well-rounded edges, to prevent the undue stress which occurs at sharp corners. The size of the plates varied in different tests, but the most satisfactory results were obtained with plates approximately 9 in. in diameter, whose edges were rounded to a radius of about 1½ in." Skinner, "Energy Loss in Commercial Insulating Material when subjected to High Potential," *Trans. Am. Inst. Elec. Engrs.*, vol. xix., 1902, p. 1049.

[1] "The action of ordinary commercial insulating material under high potential stress is usually so erratic, owing to surrounding influences, such as temperature, moisture, ventilation, etc., that a considerable number of observations are usually necessary in order to reach any satisfactory conclusions. For this reason the specific tests which are given in this paper are intended to show characteristic and not quantitative results, and are, therefore, not to be taken for other materials, or even for other samples of the same material. Individual tests are of little value except as they fit in a series, or unless the conditions surrounding them are known to the minutest detail." Skinner, "Energy Loss in Commercial Insulating Material when subjected to High Potential," *Trans. Am. Inst. Elec. Engrs.*, vol. xix., 1902, p. 1048.

" . . . . Most of us have been baffled by the erratic nature of break-down tests. . . . "—O'Gorman, "The Disruptive Strength of Insulating Materials," *Electrician*, September 20, 1901.

of even the most uniform of insulating materials. In conducting such tests, it should be kept in mind that continuous application of the voltage will often break down samples which will resist the same strain when applied for but a short interval. It is also of

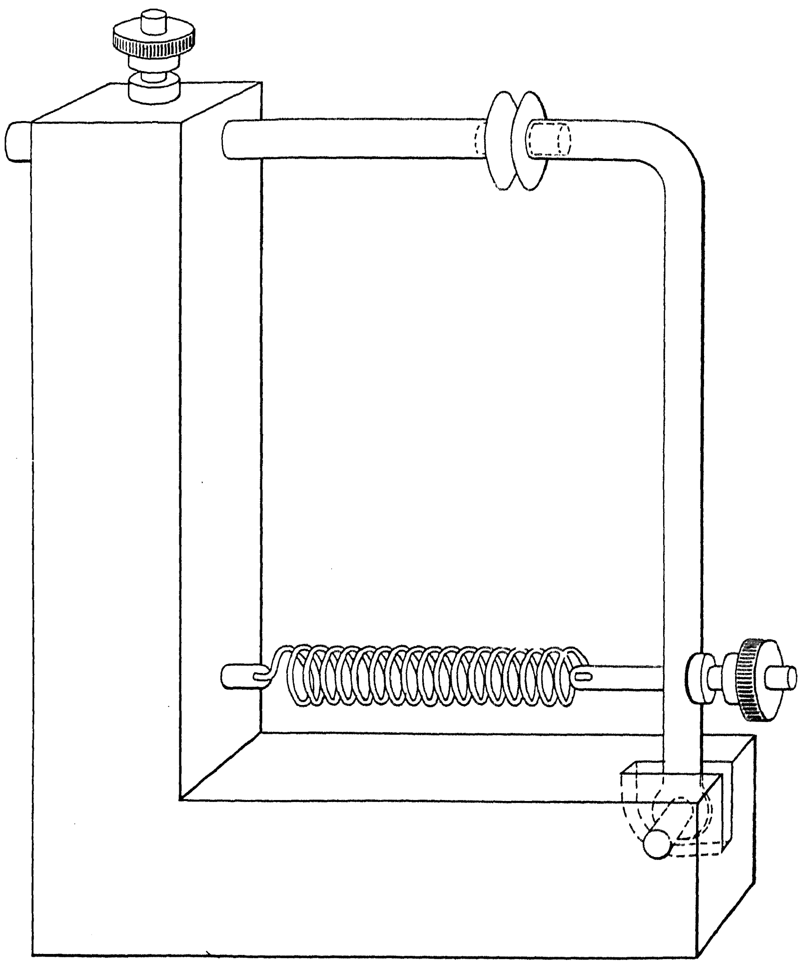


FIG. 2.—Frame for holding Samples in testing their Disruptive Strength.

special importance that the material should have been thoroughly dried prior to testing, and preserved from access of moisture during the tests. Some materials, however, which would be permanently affected by high temperatures, should preferably be dried in a vacuum oven for a long time at a more moderate temperature. It is very important that every detail regarding the conditions to

which the material has been subjected not only during, but prior to the test, should be recorded.

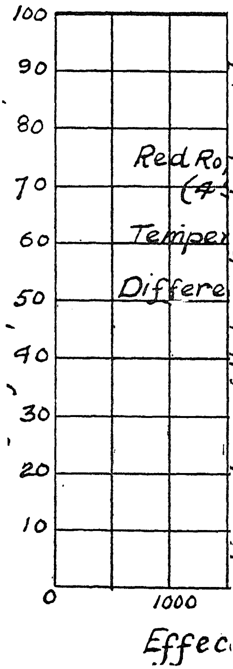
A method of testing insulating materials, which has yielded very satisfactory results, has been described on p. 43 of *Electric Generators.* The apparatus, as there described, is very crude, but contains the essentials which should be embodied in insulating testing sets for the purposes discussed. In the same treatise are also described several series of tests made with this apparatus. The materials tested were mica canvas, mica long-cloth, shellac'd paper, and red rope paper. The three former are now no longer used to any extent, having been replaced by more suitable materials. Red rope paper is still widely employed in electrical apparatus, and the description of the tests and results on this material will be repeated here as an illustration of the elaborate care necessary in obtaining any approach to a useful quantitative knowledge of the properties of a single insulating material. The paper tested averaged 0·148 mm. in thickness, and each sample tested comprised four layers. This brought the disruptive voltage within the range of the voltmeter employed, and also tended to produce more uniform results through the decreased probability of the superposition of weak places or flaws. 180 such 4-layer samples were prepared, and were baked for at least twenty-four hours at 60° Cent. prior to being subjected to the insulation test. The method of test consisted in arranging five samples between five separate testing clips, and all connected in parallel to a suitable source. The voltage was raised step by step, and at each step the number of unpunctured samples was noted. For each test carried out (*i.e.* for each duration of application of the voltage for a given temperature) four sets of five samples each were broken down. Thus the 180 samples sufficed for the nine groups of tests, the results of which are brought together in Table II. These corresponded to three different temperatures (20° C., 60° C., and 100° C.), and to three intervals of application of the voltage (5 seconds, 10 minutes, and 30 minutes).

TABLE II.—INSULATION TESTS ON RED ROPE PAPER (FOUR SHEETS).

Effective Voltage Impressed.	Duration, 5 Seconds.					Duration, 10 Minutes.					Duration, 30 Minutes.				
	Number of Samples O.K.				Per cent.	Number of Samples O.K.				Per cent.	Number of Samples O.K.				Per cent.
	Temperature, 25° Cent.														
2500	5	5	5	5	100	5	5	5	5	100	5	5	5	5	100
3000	5	5	5	5	100	5	5	5	5	100	5	5	5	5	100
3500	5	4	5	5	95	3	4	5	1	65	2	4	2	0	40
4000	4	0	1	3	40	0	0	0	0	0	1	0	0	0	5
4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Temperature, 60° Cent.														
2500	5	5	5	5	100	5	5	5	5	100	5	5	5	5	100
3000	5	5	5	4	95	5	5	5	5	100	4	2	2	5	65
3500	0	1	2	1	20	3	1	1	0	25	0	1	1	1	15
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Temperature, 100° Cent.														
2500	5	5	5	5	100	5	5	5	5	100	5	5	5	5	100
3000	5	5	5	5	100	3	2	2	3	50	3	3	2	1	45
3500	2	3	2	3	50	1	0	0	0	5	0	1	0	0	5
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

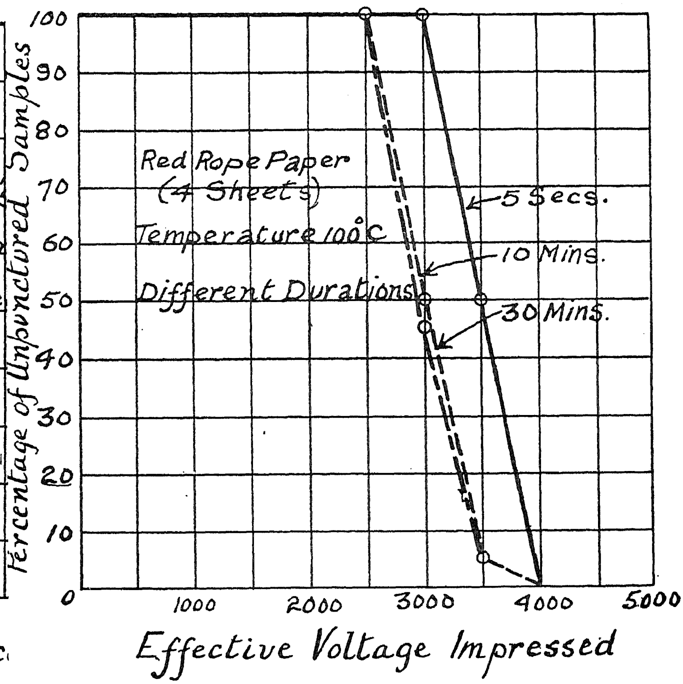
The results set forth in Table II. are plotted in the curves in figs. 3 to 8.

The results show that four 0·148 mm. sheets withstood for all these conditions a root-mean-square pressure of 2500 volts, or 4200 R.M.S. volts per millimetre for this thickness. As actually finally employed in finished electrical apparatus, this material could not be relied upon to stand a break-down test of much over half this voltage. The curves show, however, that red rope paper has a very uniform break-down strength, and that this is comparatively independent of the temperature and of the duration of application. Other tests showed it to have the property of having a break-down strength closely proportional to the number of sheets employed. This is further confirmed by the test results plotted in fig. 77. This, as we have seen, is rather an exceptional property, and

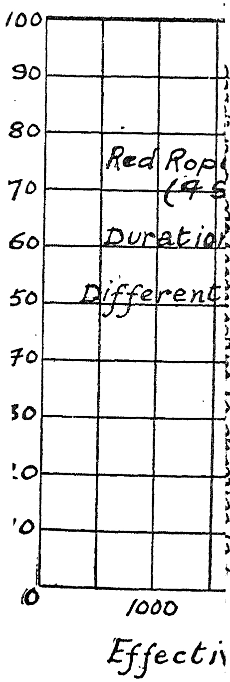


100
90
80
70
60
50
40
30
20
10
0
1000
Red Ro
(4
Temper
Differe
Effec

Fig. 5.

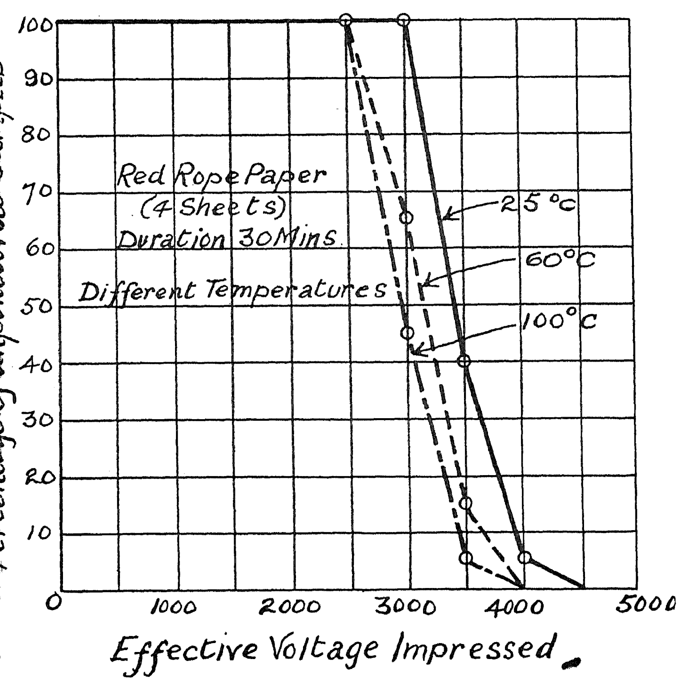


Percentage of Unpunctured Samples
100
90
80
70
60
50
40
30
20
10
0
1000
2000
3000
4000
5000
Red Rope Paper
(4 Sheets)
Temperature 100°C
Different Durations
5 Secs.
10 Mins.
30 Mins.
Effective Voltage Impressed



100
90
80
70
60
50
0
1000
Red Rope
(4 S
Duratio
Different
Effecti

Fig. 8.



100
90
80
70
60
50
40
30
20
10
0
1000
2000
3000
4000
5000
Red Rope Paper
(4 Sheets)
Duration 30 Mins.
Different Temperatures
25 °C
60°C
100°C
Effective Voltage Impressed

appears to be also inherent to red rope paper when it is used as a carrier for insulating impregnations, as is shown by the upper curve of fig. 77, which relates to oiled red rope paper. Red rope paper is of a fibrous nature, is mechanically strong, and runs very uniform in thickness, this latter being a by no means unimportant feature in practice.

It is thought that the detailed description of these tests on red

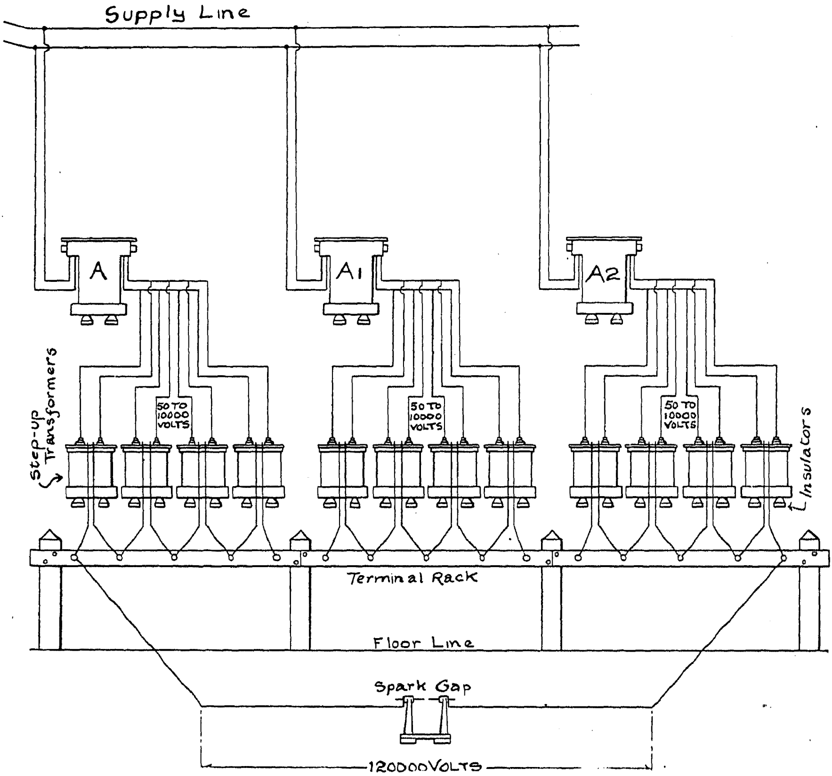


FIG. 9.—Diagram of Connections for Insulation Testing Set.

rope paper well illustrates the fact that an intelligent use of any insulating material is only possible when results, based on organised and comprehensive tests, are available. Not only should many other materials be thus exhaustively tested, but other thicknesses of red rope paper, as well as red rope paper impregnated with various other materials.

Untreated fabrics and papers generally show a much greater independence of the number of layers tested, so far as relates to the

disruptive strength per layer, than is shown by these same cloths and fabrics when impregnated with linseed oil or other insulating varnishes. The impregnation generally increases the disruptive strength per layer, but at the same time renders this value much more dependent upon the number of layers tested.[1] In the case

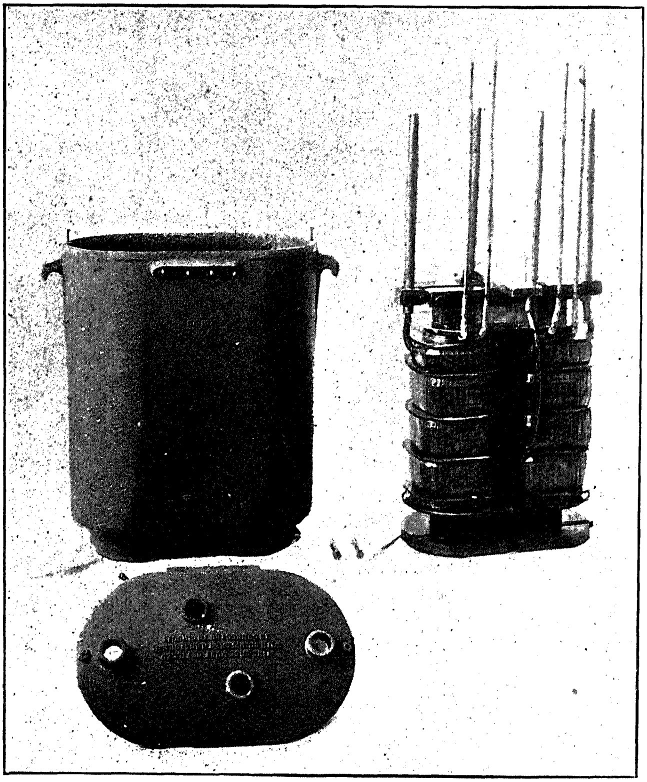


FIG. 10.—Small Testing Transformer of the General Electric Co. of Schenectady, U.S.A.

of oiled as compared with untreated presspahn, we encounter an interesting result. While the oiled presspahn is seen from fig. 75 to have a higher disruptive strength *per layer*, the thickness has so increased by soaking it in oil, that when the results are

[1] Various explanations have been suggested for the tendency toward decreased disruptive strength per millimetre for increasing thickness. One relates to the general non-homogeneity of the material owing to the decreasing saturation by the impregnating varnish as the inner strata are approached. In some cases it may be attributed to the poor thermal conductivity of the material, which heats up locally to a greater extent the greater the thickness.

replotted, as in fig. 76, in terms of the disruptive strength per mm. of total thickness, the untreated presspahn is found to have the higher disruptive strength per mm. for all thicknesses above 0·7 mm.

The Stanley Electric Manufacturing Co. and other concerns have built very useful testing sets for insulation measurements. Fig. 9 shows diagrammatically the arrangement of the connections. The three transformers A, A1, A2 are interposed between the supply line and the three groups of special step-up transformers. Such a transformer is shown removed from the case, and again,

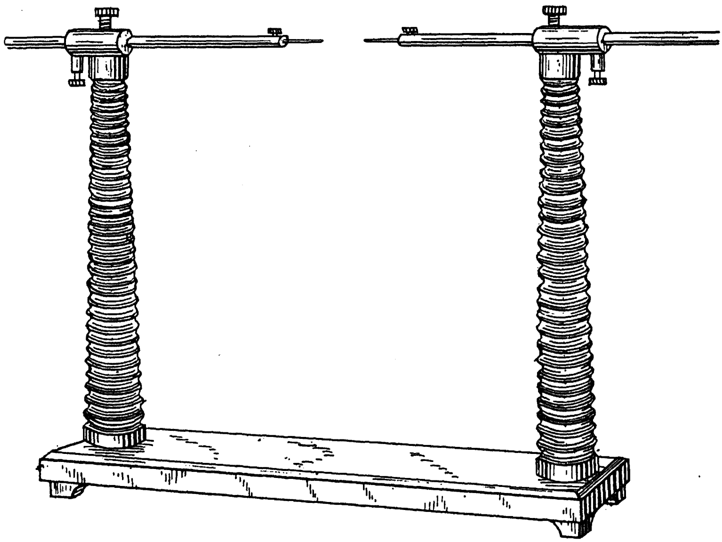


FIG. 11.—Adjustable Spark Gap.

when assembled, in fig. 10. This transformer is built for such purposes by the General Electric Co. of Schenectady, U.S.A. The twelve step-up transformers are carefully installed on wooden blocks and high-voltage insulators. By this arrangement we have the advantage that between points having a difference of potential exceeding 40,000 volts there intervenes the insulation of four transformers which have been individually subjected to thorough and severe tests. The test leads may be attached to any of the contact posts, thus providing an adjustment of steps of 10,000 volts, from 10,000 to 120,000 volts. Intermediate variations may be effected by a rheostat in the low-tension circuit. Although

the flexible test leads are not to be handled when they are alive, they should, nevertheless, be highly insulated. Before making adjustments the main switch should be open.

The adjustable spark gap which is shown in fig. 11 is used for the determination of the voltage, and the curve in fig. 12 gives the voltage corresponding to different spark lengths. The spark gap is designed to withstand a very high pressure. The base is of the

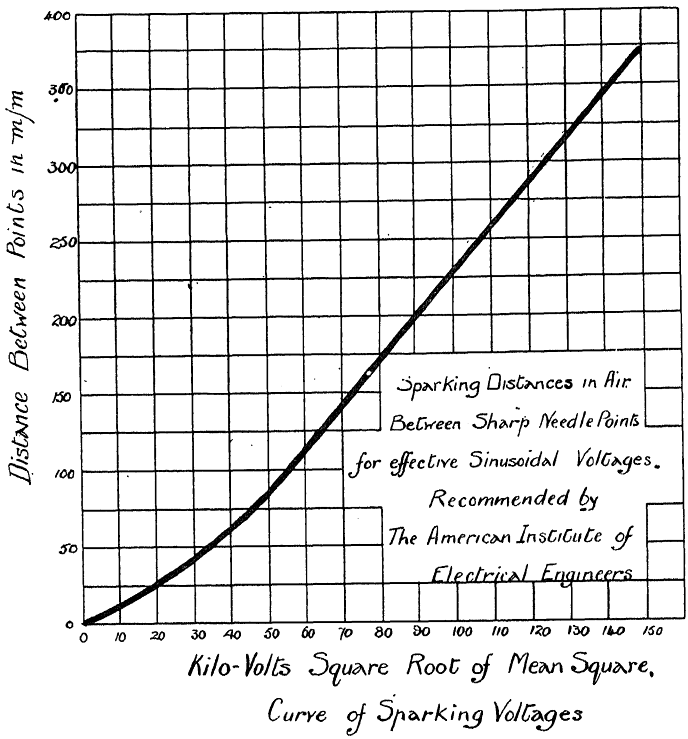


FIG. 12.

best quality hard rubber, and measures some 450 mm. × 120 mm., and is some 20 mm. thick. Extra insulation is provided by the four corner supports. The hard rubber posts carrying the adjustable terminals are fluted in order to increase the resistance to surface leakage. As alternative to such an arrangement of apparatus, a single high-voltage transformer is often employed. Although this must be very large and expensive for its output, it is generally to be preferred on the score of simplicity. Such a transformer, as

built by the General Electric Co. of Schenectady, U.S.A., is shown in fig. 13.

On the Continent, where safeguards are more rigidly enforced, a testing room is provided, to which all apparatus to be tested must be transported. Here the switches cannot be closed while the door is open, as the switch and door are interlocking. The danger

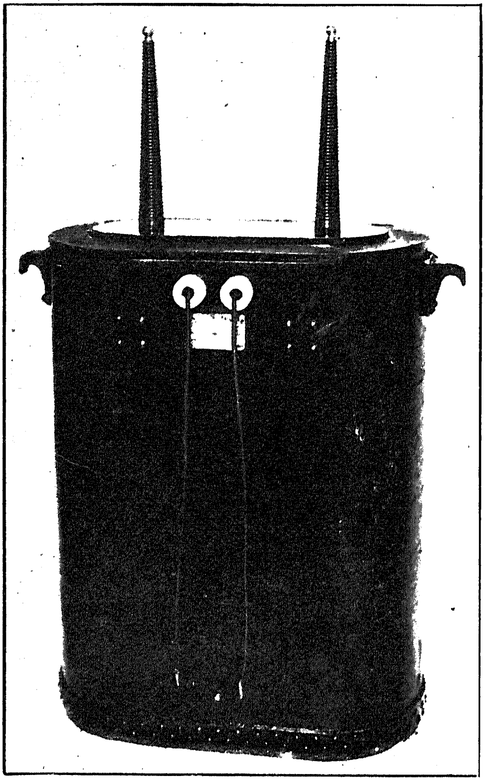


FIG. 13.—Large Testing Transformer of the General Electric Co. of Schenectady, U.S.A.

to life is thus reduced to a minimum. The transformer may be of the solenoid type, with a Kelvin electrostatic voltmeter in parallel. Such an arrangement is shown diagrammatically in fig. 14 Transportable transformers with resistances and with flexible leads which are tapped into the alternating current circuit at convenient places about the shop are largely used in this country. They ought never to be handled by inexperienced help, and should be inspected from time to time to see that the insulation of the

leads and other parts is in good order. Such a portable testing set is shown in fig. 15.

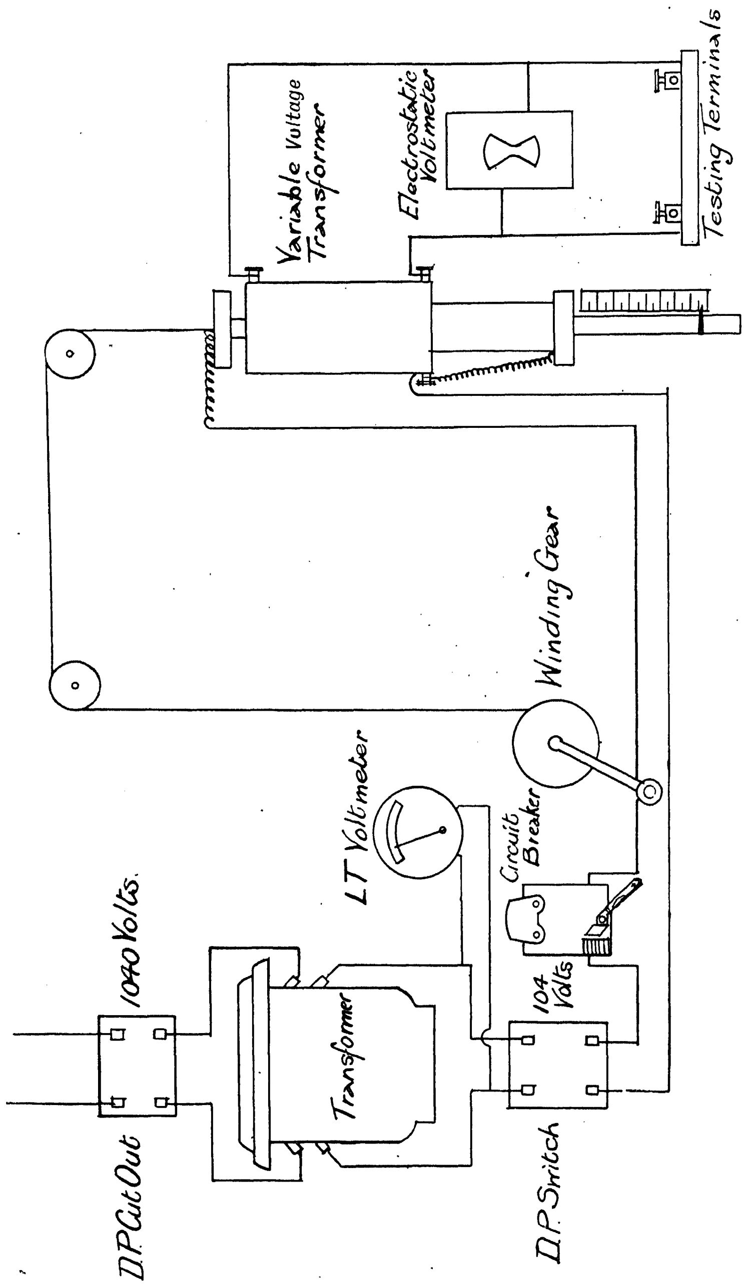


Fig. 14.—Diagrammatic Scheme of Connections for an Insulation Testing Set with Adjustable Solenoid Transformer.

Holitscher (*E.T.Z.*, 1902, p. 170) has described a thermostat designed by Köhler for testing samples at various temperatures. This is illustrated in fig. 16. The high potential testing wires are brought in through the insulating bushings S S at the two sides. The thermostat is provided with a regulating apparatus, which permits of maintaining the temperature constant within 3° Cent. above and below the desired temperature. The burners B B heat the air entering the surrounding compartment, after passing

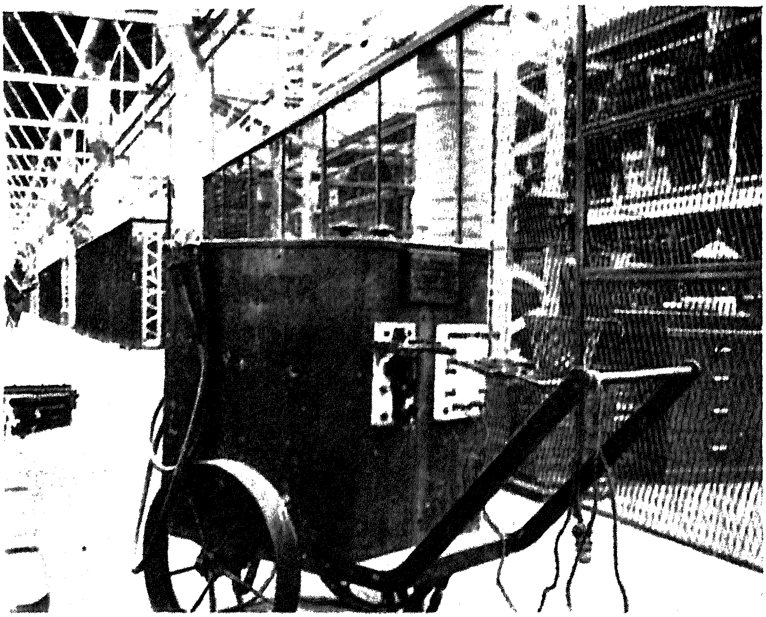


FIG. 15. Transportable Transformer and Switches for Testing the Insulation of Apparatus during manufacture.

through which the air escapes at O. The thermometer is inserted at T, the bushing being of asbestos. The steel tube R, filled with air, serves as regulator, in virtue of the capillary steel tube K communicating from R to the gas regulator R_g, by way of a U-shaped tube, containing mercury Q. The gas enters the regulator at g and leaves at a. Should the temperature become too high, the heated air in R expands and presses on the mercury, which closes the auxiliary gas inlet V and decreases the flame. When the temperature becomes too low the mercury falls and the flame increases. The path g H a prevents the complete extinction of

the flame. By suitable adjustment of H the required temperature is obtained.

A closer study of such properties as specific inductive capacity has led to the explanation of some singular phenomena. Fessen-

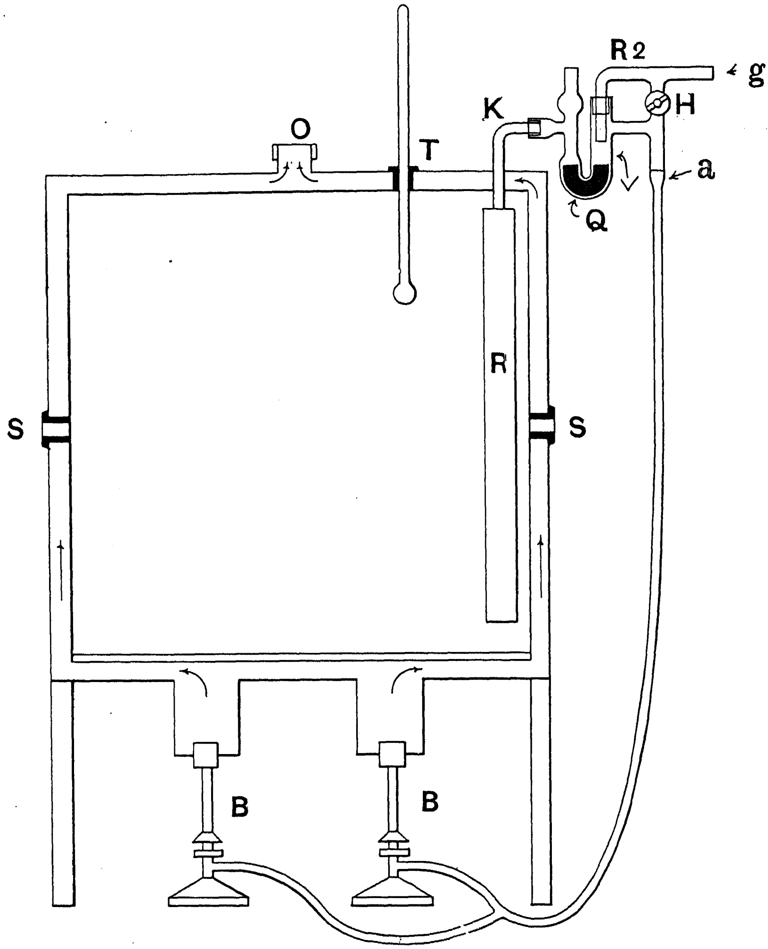


FIG. 16.—Köhler's Thermostat for Testing the Insulation of Samples at Various Temperatures.

den[1] describes an experiment with two plates (B and E of fig. 17), 1 cm. apart, attached to the terminals of a 10,000-volt alternating current dynamo. "Suppose the dielectric air to withstand 50 per cent. more than this pressure. Introduce two plates of glass (C

[1] *Trans. Am. Inst. Elect. Engrs.*, vol. xv., 1898, p. 140.

and D) with a specific inductive capacity eight times greater than air, each plate being $\frac{1}{4}$ cm. in thickness. Since the voltage divides itself up inversely to the capacitance, we shall now have 8890 volts between C and D. This being at a rate of 17,800 volts per cm., and as it only supports 15,000 volts, we shall get a spark between C and D with every reversal of the voltage, which will quickly heat the glass and make it conduct. The full potential of 10,000 will then be between C and D, and a regular arc will form. Thus we see that the introduction of a good insulator will, in all cases where an intermittent or alternating voltage is used, have the paradoxical effect of weakening the insulation, unless the whole space is filled up with the material. This weakening is not gene-

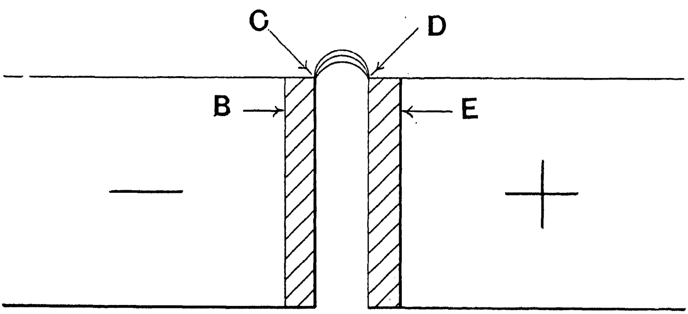


FIG. 17.—Fessenden's Experiment.

rally apparent at once, as the spark takes some time to eat its way back, and this explains why many induction coils only last for a few years of operation."

O'Gorman [1] has also described this influence of non-homogeneity of the dielectric:—"The reason for objecting to bubbles is not usually appreciated; not only does the possibility of a single bubble

[1] "Insulation on Cables," *Proc. Inst. Elec. Engrs.*, vol. xxx., 1901, p. 621. Although O'Gorman ascribes this experiment to Fessenden, it has been thought well to give it again in the former's own words, as a sound understanding of such phenomena will be more than ever essential with the rapidly-increasing refinements required in the application of insulating materials. O'Gorman, in the paper from which the above extract has been made, shows the bearings of these phenomena upon the "grading" of cables, by means of which great economies may be effected. Similar considerations should also be taken into account in the manufacture of dynamo-electric machinery, although the occasions arising for employing this particular plan will be far less frequent than in cable manufacturing.

increase the thickness of the dielectric throughout, and thus add to the cost of the cable, but even the increased thickness is not as effective as the thinner dielectric if the insulator were continuous."

"This inefficiency of the thicker material (unless the increased thickness is equal to the diameter of the bubble) is shown by an experiment which is perhaps not as well known as it deserves to be. If we arrange two conductors A C (fig. 18), at such a distance apart that the air is just able to withstand for an indefinite time, say, 10,000 volts maintained by a transformer, and then introduce between them two strips D B (fig. 18A) of glass or ebonite, the insulation breaks down, although the glass is a more volt-resisting substance than an equal thickness of air. This experiment was shown by Tesla, and was taken by him to show that ebonite was a less resisting substance than commonly supposed. The explanation,

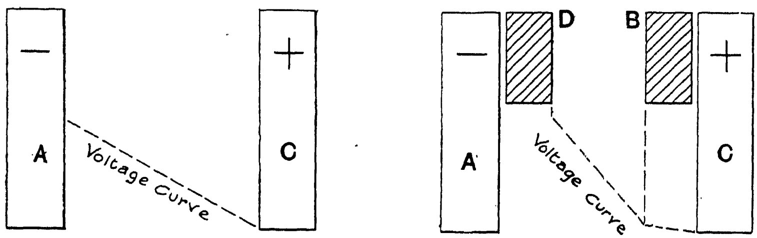


FIG. 18. FIG. 18A.
O'Gorman's Illustration of Fessenden's Experiment.

however, is very different and quite simple; the rate of fall of volts per centimetre of air is the highest the air can withstand; as glass has a higher specific capacity, the potential gradient in the glass is less steep than in the air, and the consequent increased steepness in D B punctures the air; and the heated glass thereupon soon gets hot and gives way under the alternating potentials. This experiment leads up to the idea of uniformity of texture in all classes of insulating materials which are built up in successively thin layers, especially when the layers, as in paper cables, may not be closely compacted together for fear of losing flexibility, or when the layers, as in rubber cables, have (to economise the more expensive insulators or to separate the copper from sulphur) to be composed of dissimilar compounds. With our present methods of manufacture it would seem that security is got in the one case by

seeing that the impregnating oil has approximately the same specific capacity as the paper fibre, and avoiding crumpled paper—not a difficult matter; and in the other by avoiding too great a difference between the compositions of the coats."[1]

[1] "Particles of higher specific inductive capacity in a matrix of lower specific inductive capacity tend to set themselves in the plane of highest potential slope." — "Insulation and Insulators," Harold D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.)

This explains why inequalities produce faults in the dielectric, and shows how necessary it is to have a dielectric homogeneous throughout with regard to its specific inductive capacity, in order to obtain high puncture resistance.

CHAPTER II

SOME PROPERTIES OF INSULATING MATERIALS

THE widely divergent results obtained by different investigators for the insulation strength of different materials are due to a number of reasons.

I. **Influence of Moisture.**—Even by taking great care in the preparation of the samples to be tested, it is difficult to remove all traces of moisture. It is, moreover, a question in how far materials should be dried out for testing, for this may lead to a greater sacrifice of their mechanical suppleness than is consistent with the use for which they are intended. But between the limits of drying the samples as completely as is practicable by the combined use of a vacuum and heat, and leaving them in their natural state, it is difficult to find an intermediate basis for reference.[1]

The enormous extent of the influence of moisture may be seen from fig. 19,[2] which shows, for the case of a sample of plain cotton duck, 0·38 mm. thick, the initial improvement in insulation (as measured in megohms) due to the expulsion of moisture on increasing the temperature, and also the subsequent true deterioration of the insulation at still higher temperatures. If, instead of

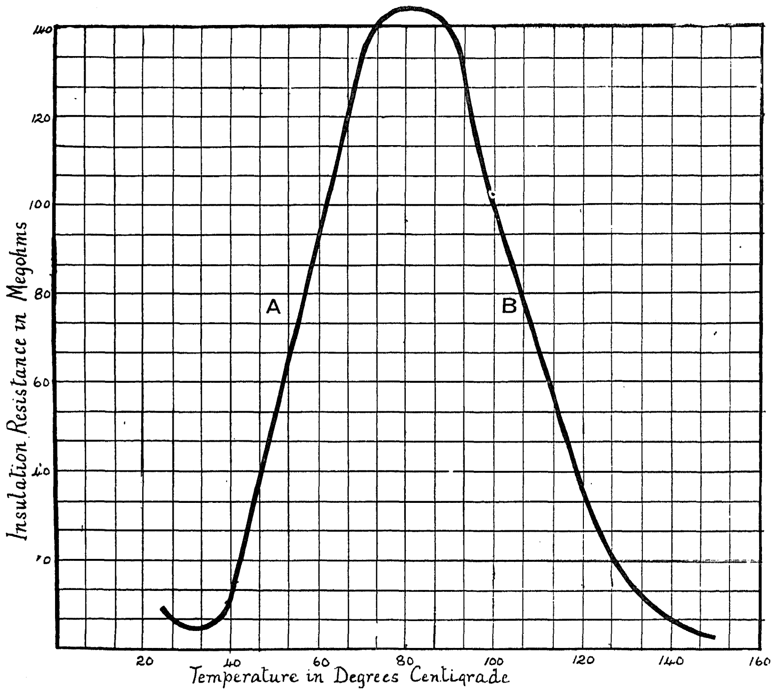
[1] Holitscher (*E.T.Z.*, 1902, p. 170) makes the following tests of insulating materials to compare their hygroscopic properties:—The sample is hung for five hours 50 cms. above the water-level of boiling water. It is then dried between blotting paper, and then subjected to a disruptive test. Samples measuring 10 cms. × 10 cms. are also weighed before and after the above process, and the percentage increase in weight is recorded. An additional test consists in noting the increase in weight after immersion in water at 20° Cent. for one hour.

[2] Taken from a paper entitled "Effect of Temperature on Insulating Materials," contributed by Sever, Monell, and Perry to the *Trans Am. Inst. Elec. Engrs.*, vol. xiii. (1896), p. 227.

measuring the insulation resistance in megohms, the disruptive strength in effective (R.M.S.) volts had been tested, the results would not have followed any such curve as that shown in fig. 19.

Another instance of the influence of drying is shown in the curves of fig. 20. In this case the disruptive strength was measured.

Perrine[1] has pointed out that even in the driest of climates



A. Improvement due to Drying. B. Deterioration due to Increased Temperature.

FIG. 19.—Curve showing effect of Influence of Moisture and of Temperature on the Ohmic Insulation Resistance of Plain Cotton Duck.

thoroughly dried wood will in two days absorb some 15 per cent. or more of its own weight in moisture, and that not less than 5 per cent. of the weight of the best compressed paper made to-day is water in dry air, and that it does not need exposure to moist air to acquire so high a percentage of moisture.

On the same occasion Mr Steinmetz contributed the following valuable comments:—

"There are three distinctly different phenomena taking place in

[1] *Trans. Am. Inst. Elec. Engrs.*, vol. xiv. (1897), p. 265.

the insulating material. The one is the changing of resistance of the insulating material proper with temperature; the second is the effect of the moisture retained by the insulating material; and the third is the chemical disintegration taking place. I may say that the separation of these three phenomena would be very desirable. A further consideration, representing a resistance increasing with the temperature, not linear but rather erratic, superimposed upon the conductivity of the insulating material proper, is the conductivity due to the moisture included by the material, and this,

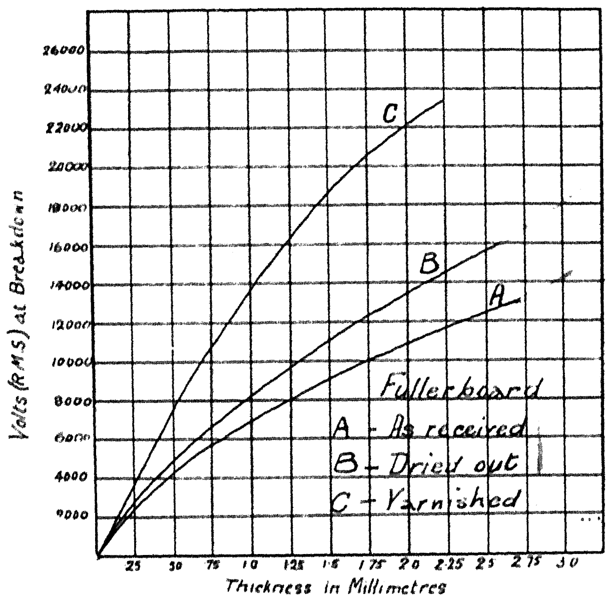


Fig. 20.—Curves showing the Influence first of Drying and then of subsequently Varnishing, on the Disruptive Strength of Fuller Board.

as before said, is entirely erratic, depending absolutely on the atmospheric conditions, and the chance of the moisture to be absorbed or to escape. Furthermore, there is a chemical disintegration taking place which changes the material, and which depends again on temperature and on time."

"I will draw attention to one feature which may very easily cause misunderstanding, namely, the effect of chemical disintegration in lowering the insulation resistance, and the effect of moisture in lowering it. There is an enormous difference in their practical bearing. Moisture, while reducing the insulation resistance, is,

within a reasonable range, perfectly harmless. It is useless to exclude it, because as soon as the electric machines come into operation they will absorb moisture again just the same."

"Thus the only object of expelling moisture by baking is to get a sufficiently high number of megohms insulation resistance, to fulfil some antiquated set of specifications."

"I am glad to state that more and more consulting electrical engineers come back from this question of the megohms insulation resistance as a guarantee of the safety of insulation of the machine, and instead of it, specify the voltage at which the insulation should not be punctured. If the insulation is fibre and is very bad it will be punctured at low voltage, and still, after baking, show an enormous insulation resistance, while a very good insulation, after long exposure to damp air as in a turbine station may be of relatively low insulating resistance, and nevertheless far superior to the infinite number of megohms which break down by disintegration or puncture at low voltage. Fortunately, now you very seldom find an electrial engineer sufficiently behind the times to request a large number of megohms. If this is the case, he gets it by baking the apparatus; otherwise baking goes more and more out of use, and its place is taken by the high voltage or puncturing test."

"Obviously moisture, while fairly harmless while in small amount, must not be excessive—that is, the armature must not be dripping with moisture, which nevertheless happens occasionally, when machinery shuts down evenings, and the dew accumulates on it overnight. Even then it usually does no harm. So you see you must distinguish between the low insulating resistance due to moisture and that due to imperfect material or chemical disintegration."[1]

II. Influence of Shape of Electrodes and Shape of Samples upon the Test Results.[2] The influence of the shape

[1] The authors are emphatically of the opinion that while there is much truth in Mr Steinmetz' remarks on this occasion, they might lead readers to belittle the great advantages obtainable by drying, and especially by the use of vacuum ovens in the construction of dynamo electric machinery.

[2] The insulation of a cable between concentric conductors or under the lead differs greatly from that of the slabs of the substance, to which inventors are always so happy to apply high voltages by means of a couple of brass balls or

of the electrodes has frequently been investigated. The most striking recent contribution on this point is contained in an article by Dr Walter on p. 874 of the *Elektrotechnische Zeitschrift* for October 6, 1904, entitled "Ueber das elektrische Durchschlagsgesetz für atmosphärische Luft." In the course of this investigation, in which an induction coil was employed, Dr Walter observed that when as electrodes there were used, on the one hand a point, and on the other a large plate, the sparking distance with the point positive was some 20 cms. as against only 4 cms. when the point was negative. The variation of the disruptive strength of materials with the shape of the electrodes could well form the subject of an elaborate systematic investigation, as, in spite of the chance observations of

plates. The brass ball test is worthless."—O'Gorman, "Insulation on Cables," *Proc. Inst. Elec. Engrs.*, vol. xxx. (1901), p. 620.

"A single strip of pure dry manilla paper, weighing 70 grammes per square metre, and about 0·004 inches (0·1 millimetres) thick, will resist 1000 volts max. (for weeks, and I think indefinitely) when tightly wrapped on a length of small wire and tightly lead-covered: four such papers impregnated with rosin and rosin oil will sometimes resist as much as 12,000 volts alternating on a length of cable; and yet twenty such papers, making a thickness of 0·08 inch (2 mm.), cannot by any means be expected to withstand 50,000 volts on long lengths, though on a yard length of 7/16, say, they frequently will. A suggested reason for the superior strength of the short piece is that in a 100-yard length the probability of a streak of dirt or moisture, or of metallic particles, or of the oil having been crushed out of the paper in bending the cable, or of a bubble, or of vacuous space, or of an irregularity in the dielectric capacity, is one hundred times greater than in the 1-yard length. Indeed, except to verify the mechanical effect of severe bending, any high pressure test on a *short* length of cable proves nothing whatever about the bulk."—O'Gorman, "Insulation on Cables," *Proc. Inst. Elec. Engrs.*, vol. xxx. (1901), p. 620.

"Dr Baur's deductions are open to question when he deals with tests made between *curved* electrodes as in a cable, and proceeds to claim that tests taken on impregnated calico between *plane* electrodes follow the same law so exactly that the curves may be superposed. In the paper to which Dr Baur alludes, I dealt a good deal with the effect of curvature, quoting Swinburne and others to show how the stress would be increased when the curvature was small, and giving a logarithmic formula which may be expected to deal with it. Indeed, Mr Russell pointed out in the discussion on Mr Siemens's paper, that, unlike Mr Siemens, he had found a very great difference in sparking distances with differently shaped electrodes, so I can only conclude that the identity between the tests taken on cables and those between flat electrodes alluded to by Dr Baur is accidental, and proves little."—O'Gorman, "The Disruptive Strength of Insulating Materials," *Electrician*, September 20, 1901.

various experimenters, which have shown that the variations due to these causes are enormous, no satisfactory series of really complete investigations is yet available.

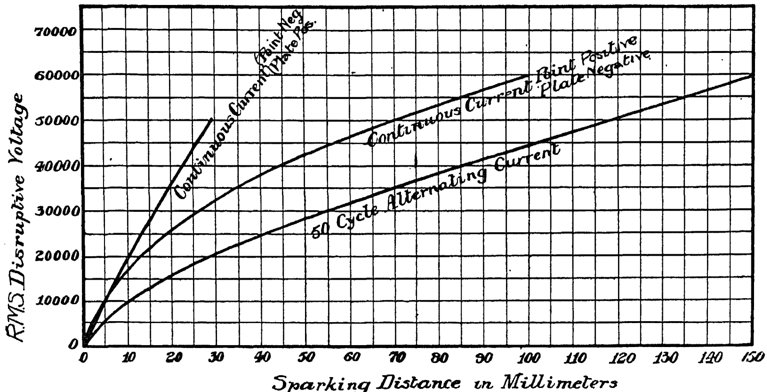


FIG. 20A.—Compagnie de l'Industrie Électrique et Mécanique's Curves for the Disruptive Strength of Air between a Point and a Plate, with Continuous-Current and with Alternating-Current Voltages.

The Compagnie de l'Industrie Électrique et Mécanique of Geneva has recently made some very interesting investigations

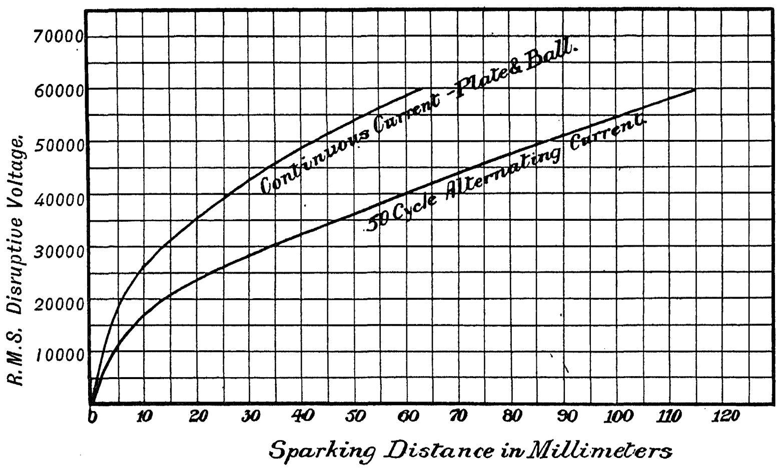


FIG. 20B.—Compagnie de l'Industrie Électrique et Mécanique's Curves for the Disruptive Strength of Air between a Plate and a Ball, with Continuous-Current and with Alternating-Current Voltages.

on the disruptive strength of air with variously shaped electrodes and with continuous-current as well as alternating-current

voltages. In the accompanying curves, the figures for the voltage, when alternating, refer to the R.M.S. voltage. The alternator had six poles and was of the smooth-core rotating-armature type, with twelve coils bound on the surface, and running at 1000 r.p.m. gave a periodicity of 50 cycles per second. The voltage curve had a flattened wave form, the maximum voltage corresponding to a given sparking distance being stated to have had but 1·26 times the values of the R.M.S. voltage given in the curves. The results are plotted in the curves of figs. 20A, 20B, 20C. The Compagnie de l'Industrie Électrique et Mécanique does not state the results obtained between pairs of pointed electrodes, merely mentioning that they were so variable as to be valueless.

The mean ratios of the continuous-current to the alternating-current sparking distances are given in Table IIA.

TABLE IIA.—RATIO OF SPARKING DISTANCES IN AIR FOR CONTINUOUS-CURRENT AND 50-CYCLE ALTERNATING-CURRENT VOLTAGES AND FOR VARIOUS SHAPES OF ELECTRODES.

	At 30,000 Volts.	At 60,000 Volts.
Ball and ball	1·6	2·5
Plate and ball	2·4	1·9
Point and ball	2·2	1·5
The balls had a diameter of 20 mm.		

III. **Influence of Method of Testing.**—This leads us to the second consideration, namely, that substances having a high insulation resistance as measured in megohms, are often of low insulation strength as measured by the disruptive voltage. The disruptive voltage is generally much the more important property in commercial work, and insulation tests nowadays much more generally relate to it than to the insulation resistances measured in megohms. (See also Steinmetz' remarks on p. 31.)

IV. **The Influence of Temperature.**—It has been shown by fig. 19 that the improvement in insulation sometimes appearing to take place at increased temperatures, is really due to the accompanying expulsion of moisture. The true insulation

resistance generally decreases enormously as the temperature increases.

This is shown in fig. 21 for the case of an insulation test on a transformer. A rise of but 60° Cent. sufficed to reduce its insulation resistance to but a small percentage of its resistance when cold. In other words, insulating substances have a very large negative temperature coefficient. In the case of this transformer, where the insulating material was a composition of

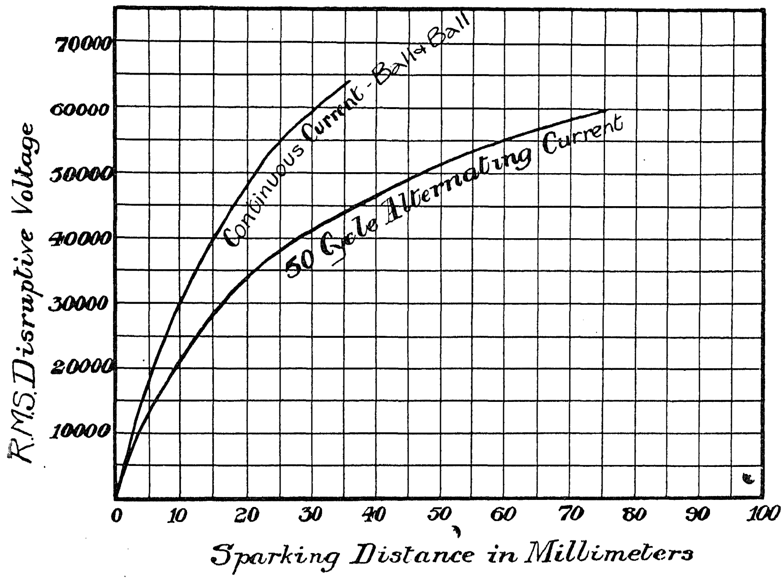


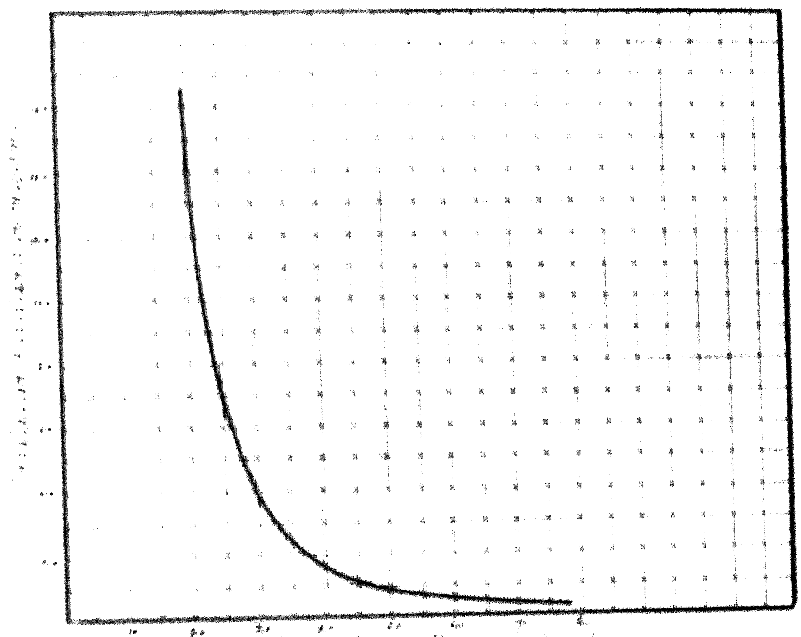
FIG. 20C.—Compagnie de l'Industrie Électrique et Mécanique's Curves for the Disruptive Strength of Air between two Balls, with Continuous Current and with Alternating Current Voltages.

mica and cloth, the transformer being immersed in oil, with which the insulation was thoroughly impregnated, the average temperature coefficient between 20° Cent. and 80° Cent. was 0·80, that is, the insulation resistance decreased .80 per cent. per deg. Cent. increase of temperature. But the ability of this insulating material to withstand the disruptive effects of very high potentials is but slightly impaired by the high temperature. This is another instance of the importance of distinguishing carefully between the ability to withstand the application of high voltages and the insulation resistance as measured in

[illegible] The insulation resistance [illegible] returns to its [illegible] value when the transformer is again cold.[1]

[illegible] curves showing the dependence of the [illegible] strength of [illegible] paper and oiled linen upon the temperature.

[illegible] the harmful influence upon many



[illegible] Effect of Temperature on a Transformer's Insulation Resistance. The voltage used for testing ranged from 20 to 100 volts. Rise of temperature [illegible] transformer coils.

[illegible] even fairly moderate temperatures [illegible] *Am. Inst. Elec. Engrs.* [illegible]

[illegible] other facts in connection with cellulose as [illegible] which I think have made it less desirable than other

[1] [illegible] referring to the influence of temperature on [illegible]

[illegible] at high temperatures [illegible] the Nernst lamp, where, after [illegible] high temperature for the glower part, one had [illegible] later for high temperatures for the heater [illegible] Society, April 16, 1903.)

materials. It is a substance which is not by any means stable at high temperatures; even a temperature below 100° C. runs it down or carbonises it slightly, so that finally it becomes an entirely different chemical substance. Some experiments were

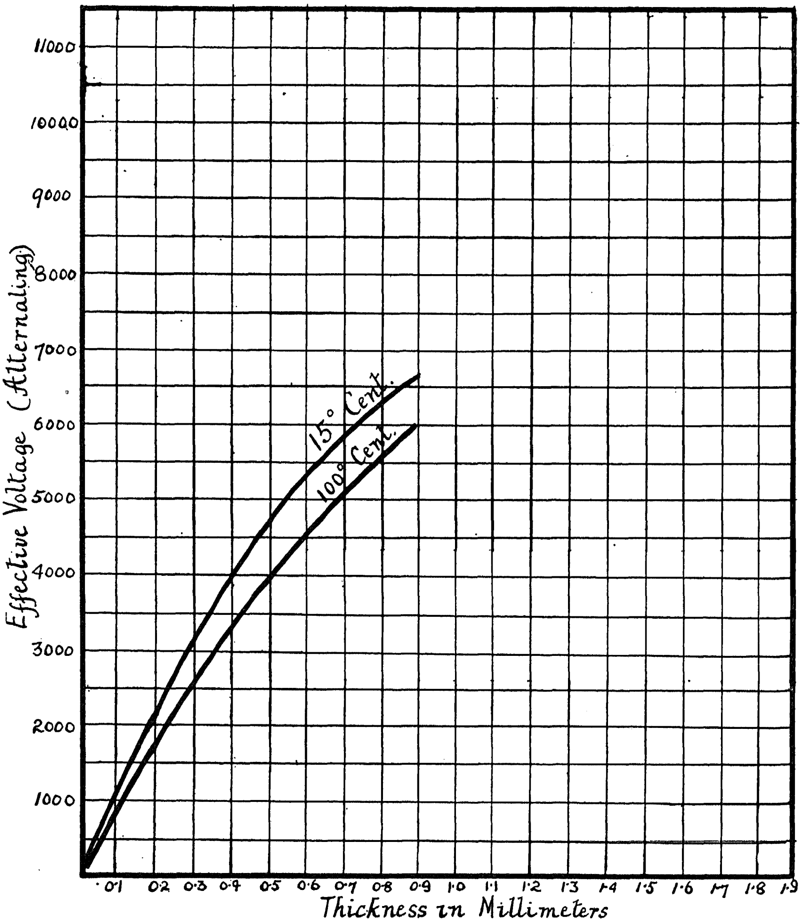


FIG. 22.—Tests of the Disruptive Strength of Ochre Brown Paper ($1\frac{1}{2}$d. per lb.). (Plotted from curves in which each point was a mean of five tests.)

made several years ago—I think as much as ten years ago, for that matter—in the Thomson-Houston factory. We subjected cotton-covered wire to varying temperatures for long periods of time, and found that even at 100° C. there was a gradual deterioration, and that at any point above 100° C. it was pretty

rapid. The cotton turned brown, and showed every evidence of a permanent loss of water and an increase of carbon relatively to the hydrogen and oxygen."

The deterioration of cotton coverings at high temperatures may

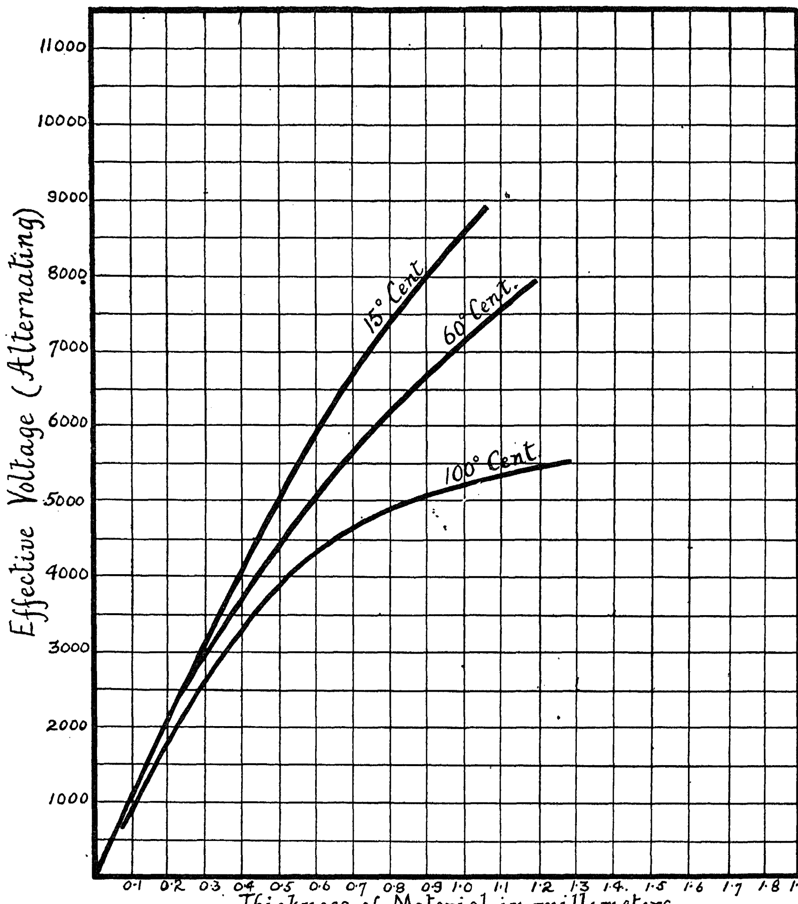


FIG. 23.—Tests on the Disruptive Strength of Oiled Linen at Various Temperatures.

be materially decreased by impregnating them with suitable varnishes.

Farrington,[1] in describing his search for an insulating compound suitable to withstand any condition to which it is likely to be

[1] "Defective Machine Insulation," Franklin Inst., March 12, 1903.

subjected, thus very strikingly emphasises the importance of the capacity to withstand high temperatures :—

"The designer of a motor never can tell which one of his machines will be located in the hottest corner of a rolling mill, or whether his generator may have some day to stand the heat of a torpedo boat engine-room with the ventilating apparatus broken down, or an emergency overload in ordinary practice."[1] In consideration of these possibilities he "wound a coil of double cotton-covered wire about a steel rod, saturated the coil with insulating compound, withdrew the steel rod, inserted in its place an ordinary thermometer, put current through the coil *via* water resistance until the coil was so badly heated as to give off dense volumes of smoke, and if by weighing it was found that a coil did not lose more than 10 per cent. of its compound, it was safe to decide that such material would stand hot service in overloaded machines. An insulating compound should have such a high melting point."[2]

In these investigations Mr Farrington encountered a "curious

[1] "It may be noted here what temperatures may be expected under working conditions. The writer knows of one or two electric lighting stations where the temperature is not infrequently about 100° F., and with the usual 70° F. rise of temperature stipulated in most specifications we get 170° F. as the final temperature. This, it should be noted, is only at points convenient of reaching, and consequently internal parts of the windings will be considerably higher. It is certain, therefore, that insulating materials should not melt or have their insulating properties deteriorated under a temperature of at least 212° F. Even this will probably leave no margin. Insulating materials should be tested throughout the working limits of temperature, as some lose their previously high insulating properties when the temperature is raised to the working limit, whilst the insulation in some cases chars or carbonises. This is a very important point, as many engineers insist that pressure tests on plants must be made immediately after a lengthy full-load run, and sometimes an additional run of two hours on 20 or 30 per cent. overload. The machine will, of course, be still warm, and most likely warmer than at any time on load, as the cooling effect of the revolving parts has then ceased."—*Elec. Eng.* for September 16, 1904, p. 412. "On Insulation."

[2] This method, however, does not take into account the effect of repeated heating and cooling, often many times per hour. It is this alternate heating and cooling which is so disastrous. His method also gives no indication whatever of how the compound withstands rapid heating, such as would occur in a machine started from no load to say 50 per cent. overload in a very short time. It is this last which proves how a dielectric is able to dissipate the heat generated in it. Farrington's method simply seems to be an indication of what temperature the compound can be carried to before the cotton chars.

inability on the part of a good many electricians to distinguish a difference between old-fashioned tests and modern conditions." They "wanted to test insulation melting points by the same method by which oil chemists find the melting point of an oil or wax, but we found that test so misleading as to make it necessary to make our tests exactly like the conditions of actual service."

V. Influence of Time—Ageing.—The influence of the time

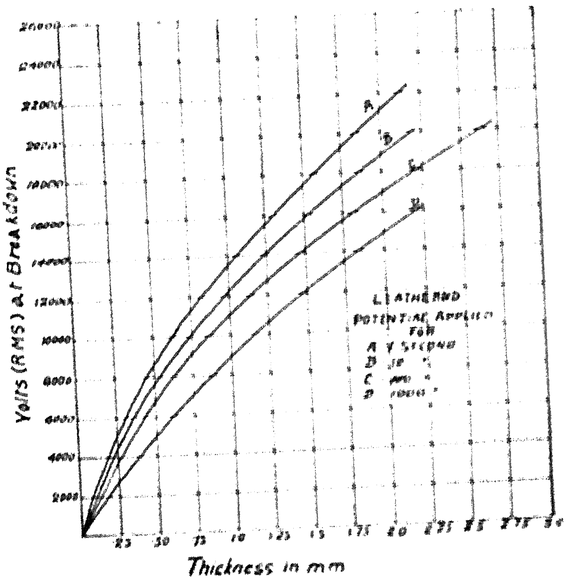


FIG. 24.—Curves showing, for Leatheroid, the Influence of the Duration of Application of the Testing Voltage.

of application of the testing voltage has already been shown for the case of red rope paper in the curves of figs. 3 to 8. For leatheroid it is seen in the curves of fig. 24, deduced from data contained in a publication issued by the Dielectric Manufacturing Co., of St Louis.

But it might be that an impregnating compound, on reaching a temperature a little below that at which the charring takes place, begins to actually burn itself, which would be undesirable, and might be mistaken for the cotton charring. A better way for testing an impregnating compound is to subject samples to many variations of temperature, noting the loss in weight, if any, and also the puncture resistance, and whether the compound tends to leave the cotton or make it brittle. The loss in weight may be due to moisture in the cotton, which has not been thoroughly dried, and is driven off on continued heating.

The altogether different phenomenon of "ageing" is illustrated by fig. 25, taken from the same publication.

VI. The Effect of Varying Thickness, and Baur's Law for "electrical breaking strength."—It has already been pointed out that for most insulating materials the thickness must be

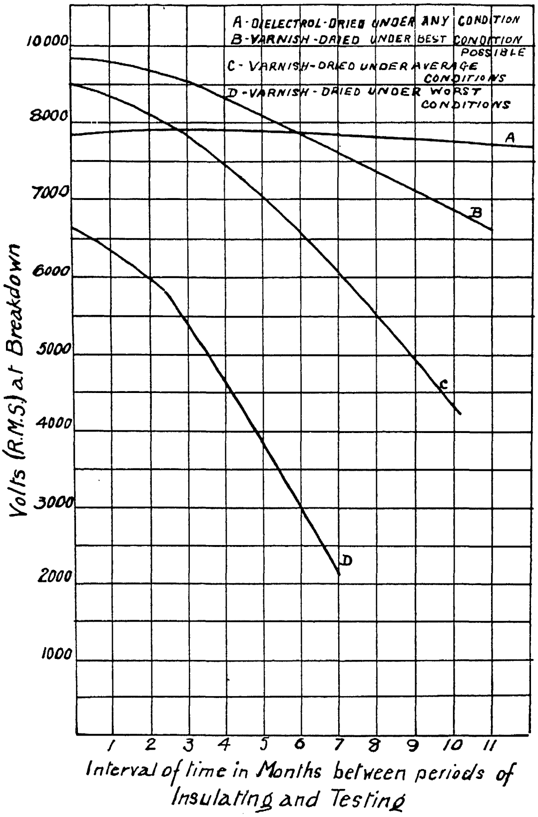


FIG. 25.—Curves showing the "Ageing" of Insulating Varnishes.

It is stated by the Dielectric Mfg. Co., who have published these tests, that in the case of Curve A the Dielectrol was in continued contact with copper on the inside of coils. They claim that while the initial insulation of Dielectrol is lower, the time element affects it less than is the case with other varnishes.

increased more rapidly than the increased disruptive strength desired. This is mainly due to phenomena as yet but slightly understood. Sometimes, however, as in the case of vulcanised fibre and sheet leatheroid, and of hygroscopic materials in general, it is partly due to the difficulty of drying out the inner portions

and to the difficulty in obtaining uniform composition throughout the thickness of the sheet. Thus some tests on sheet leatheroid gave the following results :—

TABLE IIB.—DISRUPTIVE STRENGTH OF SHEET LEATHEROID.

Thickness in mm.	Insulation strength in volts.	Insulation strength per mm.
0·397	5,000	12,600
0·795	8,000	10,000
1·19	12,000	10,000
1·59	15,000	9,400
3·17	15,000	4,750

On the other hand, tests have been made on some few materials which appear to show an increase in dielectric strength in greater proportion than the corresponding increased thickness. Thus, on some samples of composite sheets of white mica, alternating with sheets of paper specially prepared so as to be moisture-proof, the following test results have been obtained :—

TABLE IIC.—DISRUPTIVE STRENGTH OF COMPOSITE SHEETS OF WHITE MICA ALTERNATING WITH SHEETS OF PAPER.

Thickness in mm.	Insulation strength in volts.	Insulation strength per mm.
0·127	3,600 to 5,860	28,300 to 46,200
0·178	7,800 to 10,800	44,000 to 61,000
0·228	8,800 to 11,400	38,600 to 50,000
0·279	11,600 to 14,600	41,500 to 52,500

At first the dielectric strength increases more rapidly than the thickness, and then remains, on the whole, fairly proportional to the thickness.[1] The better average distribution in such built-up mica insulations doubtless contributes somewhat to this result. Other composite mica materials also show a dielectric strength, increasing somewhat more rapidly than the thickness. Thus

[1] It is claimed that with some insulating compositions (amongst which berrite may be mentioned) there is an increase of disruptive strength per millimetre thickness for the first few layers, and then the curve bends off for succeeding layers, showing a puncturing resistance per millimetre, gradually decreasing with increasing thickness. This is difficult to explain. The same phenomenon is sometimes found with manilla paper. Curves of berrite are given in fig. 84a.

Arnold, on p. 52 of vol. ii. of *Die Gleichstrommaschine* (Julius Springer, Berlin, 1903), states that for "Megohmit" the manufacturers quote the following average values:—

TABLE IID.—DISRUPTIVE STRENGTH OF MEGOHMIT

Thickness in mm.	Insulation strength in volts.	Insulation strength per mm.
0·25	8,000	32,000
0·40	12,500	31,300
0·60	20,500	34,200
0·80	27,500	34,400
1·0	36,000	36,000

There has lately been discovered a most remarkable and important property of insulating materials, in virtue of which a much thicker layer of a given insulating substance may be broken down with a given voltage, than is otherwise possible. A drop of wax is poured upon one surface of the sample to be tested. After the wax is cool it is perforated with a fine needle. At distances of 1 mm. from either side of the sample thus prepared, and in line with the perforation in the wax, the electrodes are set, and the testing voltage applied to them. This method, and its application to the more precise testing of insulating materials, are described by Dr Walter in the *E.T.Z.* for September 24, 1903, p. 796. Some time prior[1] to this, however, considerable attention had been given to the discovery that a drop of oil similarly arranged on a slab of mica greatly decreased the disruptive strength of the mica. This was in some quarters attributed, and with an appearance of reason, to a deteriorating influence of oil on the insulating properties of mica. The chief objection to this explanation is, that some considerable time is required to effect any apparent mechanical change on mica by contact with oil, whereas in the experiment referred to, any piece of fresh, sound mica showed a materially less disruptive strength when tested in this manner.

Dr Walter advocates the use of the method for several reasons, one of which is that with a given maximum available voltage thicker samples may be tested. A more important advantage is

[1] See Chapter V. for further discussion of this phenomenon of the action of oil on mica.

the greater precision and consistency of the results obtained. The possibilities of the method are so great that we shall describe it in considerable detail.

Dr Walter, in the article to which reference has been made, points out the great differences in specific resistance given for different substances which are not very different as regards their strength to resist the applications of high voltages, which latter he designated as their "disruptive strength." As an instance he mentions the cases of glass and hard rubber. In Uppenborn's *Kalendar* for 1903, p. 61, the specific resistances of glass and hard rubber are given as 6,600,000 and 3,600,000,000 megohms per centimetre cube respectively, hard rubber thus having over 500 times the specific resistance of glass.[1] On the other hand, tests of the "disruptive strengths" of these two materials showed hard rubber to have a value but 50 per cent. greater than glass. Such observations led Dr Walter to devise the method under consideration for measuring the "disruptive strength" of insulating materials. Dr Walter found that one could by this method perforate quite a thick layer of any highly insulating substance. He pours a drop of hot wax on one surface of the sample to be tested, so as to form a patch of about 2 cm. diameter and 2 mm. thickness. When the wax is completely cooled, it is perforated near its centre by a fine needle right through to the surface of the plate to be pierced. Two electrodes of any suitable form, and connected with the source of voltage, are brought to within about 1 mm. on either side of the plate, and in line with the perforation in the drop of wax. A relatively low voltage suffices to perforate a sample thus prepared.

Dr Walter prefers to use as unit, the length of spark gap in air, which corresponds to the break-down voltage. This he measures between two needle points in parallel to the electrodes employed for perforating the sample.

The process may be illustrated by an example:—

A hard rubber plate measuring 50 cms. by 50 cms. and 4 mm. thick could not be broken down by a voltage corresponding to a

[1] The greater surface leakage over glass as compared with hard rubber is probably partly responsible for the great apparent difference generally observed. Glass condenses moisture far more rapidly than rubber.

spark 40 cms. long in air. The voltage equivalent to a 10 cm. spark applied for but a few seconds sufficed to perforate the sample when arranged by the above-described method. For thinner plates of the same material, correspondingly shorter spark gaps sufficed. By means of a 35 cm. spark it was possible to perforate a plate of hard rubber 16 mm. thick. Plates of glass, porcelain, and mica were similarly perforated. These tests afford proof that when, intentionally or unintentionally, an electric stress is thus concentrated upon a single point of an insulator, its perforating power is enormously increased. This is a phenomenon of great importance, and throws light upon the cause of many otherwise inexplicable insulation break-downs.

Dr Walter's experiments led him to two very important conclusions: first, that for a plate of a given thickness of an insulating material, a definite minimum voltage (spark length) which is capable of perforating the plate may be determined by this method. The second conclusion is that this voltage is directly proportional to the thickness of the plate; *i.e.* the true disruptive strength is directly proportional to the thickness of the insulating material.

In view of these facts, Dr Walter proposes that the "disruptive strength" of any insulating material shall be defined as "the smallest spark length in air between pointed electrodes and measured in centimetres, which suffices to perforate within one minute the majority of samples tested, the results being reduced to one centimetre thickness of the material in question."

The samples may be of any suitable thickness, but the specific dielectric strength is reduced to that of a sample of one centimetre thickness, and this is practicable in view of the direct proportionality between thicknesses and dielectric strength, which appears to be established by Dr Walter's tests. It was found that the source of voltage supply was of little consequence except that, in order to avoid development of heat at the point of the sample where the perforation ultimately occurs, the number of sparks per second should be maintained low. Dr Walter chose 20 sparks per second for his work. Were an appreciable temperature increase to be permitted, the phenomenon of decrease of disruptive strength with increasing temperature

would modify the results. Rhumkorff coils were used in Dr Walter's tests; the special type and capacity was found to be without influence upon the results, which were also unaffected by the presence or absence of Leyden jars.

The arrangement of the apparatus is shown diagrammatically in fig. 26. A and B are the poles of the Rhumkorff coil.

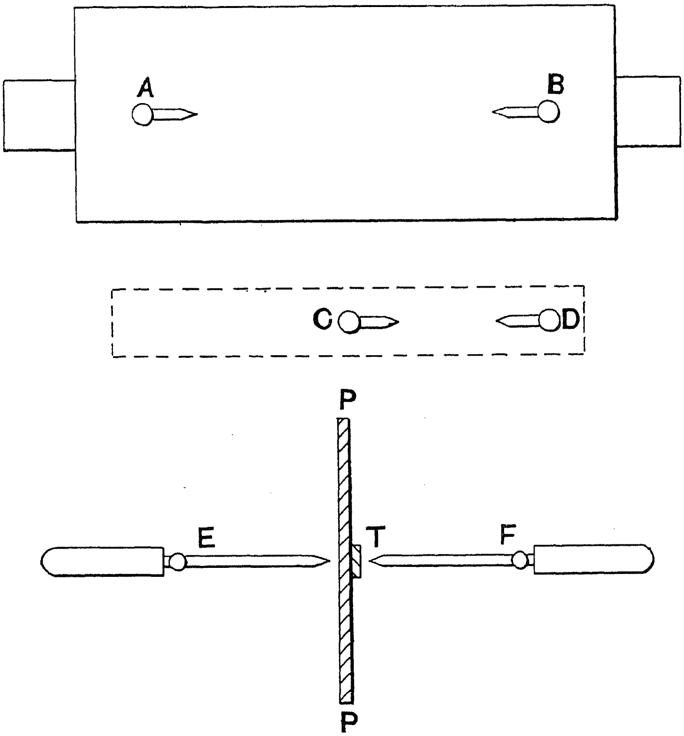


FIG. 26.—Diagrammatic Representation of Apparatus for Dr Walter's "Piceïn-drop" Method of Determining the Disruptive Strength of Insulating Materials.

Pole points are attached at A and B as shown, thus fixing a maximum spark gap to protect the inductorium from injury. By means of the adjustable needle-points C and D the desired gap is obtained. These are connected by highly-conductive, non-inductive leads, with the testing electrodes E and F, which are mounted upon hard rubber rods from 20 to 40 cms. long. P P is the sample to be tested, and T is the patch of wax on the surface opposite the positive electrode F. It has been ex-

perimentally found that the perforating power is considerably greater in this direction. Although the polarity is important, the particular *form* of the electrodes E and F is of but slight influence. As an example of the extent of the influence of the polarity, it may be mentioned that the 4 mm. thick hard rubber plate above mentioned was pierced in 2, 1, and 3 seconds respectively, in three tests, when the waxed side was opposite the positive electrode, whereas 55, 69, and 31 seconds respectively were required when it was opposite the negative electrode. Samples prepared with *both* sides coated with perforated wax had a much greater dielectric strength than when only one side was thus prepared.

When all is arranged, a prepared (waxed) portion of the sample is subjected to a given spark length for two minutes. If it has not broken down, a second spot is tested at the same spark length. If this also does not break down, it is tested at an increased spark length; and if not perforated, a third spot is tested; and this is continued until, after a sufficient number of perforations of fresh spots has finally been achieved, the "relative critical" spark length is obtained. The "absolute critical" spark length, or the "disruptive strength," is obtained by reducing the results, by proportion, to terms of a sample of one centimetre thickness.

In the first tests, wax and stearine were used in preparing the samples. These were ultimately found unsatisfactory, as they did not adhere firmly to some materials. A composition which Dr Walter named "Piceïn," supplied by the Hamburg Rubber Co., was ultimately found preferable. This is a black, tough, and adhesive material, with a melting point of 72° Cent. Even when cold, "Piceïn" sticks to substances of all kinds. It is, however, preferable to apply it hot.

The most convenient form for the sample of insulating material is in plates of 30 cm. by 30 cm., and from 1 mm. to 5 mm. thickness, according to the disruptive strength. By suitably marking off this plate, 16 drops, 6 cms. from one another, may be prepared, and this number amply suffices for a determination of the disruptive strength.

In perforating the drops of wax, care must be taken not to

penetrate into the samples; and in order to remove the needle without disturbing the surrounding wax, it must be carefully turned a few times before withdrawing it.

Dr Walter finds, by comparing his results with the results obtained in practice with high-tension alternating currents, that a 10 cm. spark length is equivalent to 50,000 effective (R.M.S.) volts.

In Table III. is given a summary of the test results obtained by his method, and published by Dr Walter in the article to which reference has been made.

TABLE III. DR WALTER'S TESTS ON THE DISRUPTIVE STRENGTH OF VARIOUS MATERIALS BY THE "[illegible]" METHOD.

Material.	Disruptive Strength expressed in Ratio of Spark Length to Thickness of Sample	Disruptive Strength expressed in R.M.S. Volts per mm. Thickness of Sample
Pure hard rubber	20 to 77	10,000 to 38,500
Common glass	16 to 18	8,000 to 9,000
Lead glass	11	5,500
White alabaster glass	23	11,500
Black alabaster glass	17	8,500
Ordinary porcelain for table ware	15 to 19	7,500 to 9,500
Hard porcelain from Hermsdorf	18 to 21	9,000 to 10,500
Marble	13	6,500
Galalith	12 to 17	6,000 to 8,500
Stabilit	19 to 35	9,500 to 17,500
Homogeneous mica	35 to 57	17,500 to 28,500
Resin	22	11,000
Wax	23	11,500
Paraffin	23	11,500
Soft rubber	37	18,500

In 1901[1] Baur announced that he had discovered the law of disruptive strength of dielectrics to be as follows :—

"Every dielectric, whatever its thickness be, requires a certain voltage to break it down, and this is proportional to the two-thirds power of its thickness." Baur expresses this relation by the formula—

$$V = cd^{\frac{2}{3}}$$

in which—

d = the thickness of the insulation measured in millimetres.

V = the potential difference of the alternating current measured in volts.

c = a constant representing the potential difference necessary to break down a thickness of 1 mm. of the insulation, and is by Baur called its "electrical breaking strength."

Quoting from Baur's article—

c "can be considered as a new addition to the properties of matter. If the law is proved to be true for all dielectric substances, it is only necessary to make a test of a piece of 1 mm. in thickness to obtain the whole curve for any dielectric substance."

Dr Baur gives in Table IV. the values of c, the "electrical breaking strengths" of various materials :—

TABLE IV.—BAUR'S VALUES FOR THE "ELECTRICAL BREAKING STRENGTH" OF VARIOUS MATERIALS.

Impregnated jute	2,200 volts.
Impregnated calico	2,200 „
Dry ordinary air	3,300 „
Vulcanised india-rubber of good quality	10,000 „
Empire cloth	12,500 „
Fuller board	19,000 „
Mica	58,000 „

Recently Dr Baur has returned to this subject,[2] discussing it in the light of further experimental investigations.

For air, Dr Baur obtained the results given in Table V.

[1] *Electrician*, September 6, 1901, p. 759. "On the Electric Strength of Insulating Materials," by C. Baur.

[2] "Das Gesetz der elektrischen Durchschläge," von C. Baur, *E.T.Z.*, 1904, Heft 1, p. 7.

TABLE V.—BAUR'S RESULTS FOR THE "ELECTRICAL BREAKING STRENGTH" OF AIR.

Spark Length in mms.	Disruptive Voltage.		Difference in per cent.
	Observed.	Calculated from formula $V=cd^{\frac{2}{3}}$ for $c=3300$ volts.	
0·67	2,000	2,500	− 20
1·59	4,000	4,500	− 11
2·53	6,000	6,100	− 1·7
3·60	8,000	7,800	+ 2·4
4·80	10,000	9,400	+ 6·3
6·46	12,000	11,500	+ 4·2
10·20	15,000	15,600	+ 3·8

These results agree closely with the results obtained in 1888 by Warren de la Rue and H. Müller (Mascart and Joubert, vol. ii. p. 187). Their tests were made with battery currents and plate electrodes, and for spark lengths of from 0·21 to 3·38 mm., and their results give for the value of the "electrical breaking strength" for air—

$$c = 3400 \text{ volts.}$$

The analysis of some tests made by Lord Kelvin, also with battery currents and plate electrodes, and for spark lengths of 0·025 to 1·5 mm., gave for air—

$$c = 2700 \text{ volts.}$$

As an approximate mean value from all these different investigations, Baur takes for air—

$$c = 3000 \text{ volts}$$

for plate electrodes.

Baur then analysed the American Institute tests, which were made with sharp needle-points. Taking $c = 2400$ volts, he obtains between observed and calculated results the comparison set forth in Table VI.

Thus, although pointed electrodes require a less voltage than plates for breaking down air, the difference is not so great as is generally believed.

The constant, c, also increases somewhat for air, with increasing distance between electrodes.

TABLE VI.—THE DISRUPTIVE STRENGTH OF AIR WITH SINE WAVES AND SHARP-POINTED ELECTRODES.

Spark Length in mm.	Disruptive Voltage.		Difference in per cent.
	Observed.	From Formula $V=cd^{\frac{2}{3}}$ for $c=2400$ Volts.	
5·7	5,000	7,600	−35
11·9	10,000	12,500	−20
25·4	20,000	20,700	− 3·4
41·3	30,000	28,700	+ 4·5
62·2	40,000	38,000	+ 5·2
118	60,000	58,000	+ 3·6
180	80,000	77,000	+ 4·0
244	100,000	94,000	+ 6·3
301	120,000	107,000	+12
354	140,000	120,000	+17
380	150,000	126,000	+19

In an article entitled "Ueber das elektrische Durchschlagsgesetz für atmosphärische Luft," published on p. 874 of the *Elektrotechnische Zeitschrift* for October 6, 1904,[1] Dr Walter criticises Baur's law for the "electrical breaking strength" so far as relates to air, and himself proposes the law that

$$V=a+b\,.\,d,$$

in which a and b are two constants and d has the same significance as in Dr Baur's formula, namely, the thickness of the layer of air in millimetres. Dr Walter maintains that his law holds for pointed electrodes, at least for values of d, of from 50 to 450 millimetres. In support of this, Dr Walter has taken the American Institute values (employed by Baur in Table VI.), and has arranged the comparison set forth in Table VIA., in which d is the distance in millimetres, $V_{obs.}$ the observed R.M.S. value of the disruptive voltage, V_B values by Baur's formula, Δ_B the percentage difference between the preceding two values, V_W the value by Walter's formula, which for these conditions takes the form

$$V=17{,}000+350\,d,$$

and Δ_W the percentage difference between the observed results and the values obtained by this formula. The agreement by Dr Walter's formula is very good indeed.

[1] See Note, p. 68.

TABLE VIA.—WALTER'S COMPARATIVE TABLE FOR THE DISRUPTIVE STRENGTH OF AIR.

d in mm.	$V_{obs.}$	$V_{B.}$	Δ_B in per cent.	$V_{W.}$	Δ_W in per cent.
5·7	5,000	7,000	−35	...	...
11·9	10,000	12,500	20	...	...
25·1	20,000	20,700	− 3·4	...	...
41·3	30,000	28,700	+ 4·5	31,460	4·9
62·2	40,000	38,000	+ 5·2	38,770	+3·1
118	60,000	58,000	+ 3·6	58,300	+2·8
180	80,000	77,000	+ 4·0	80,010	0·1
244	100,000	94,000	+ 6·3	102,600	2·6
301	120,000	107,000	+12	122,600	2·6
354	140,000	120,000	+17	140,900	0·6
380	150,000	126,000	+19	150,000	0·0

Dr Walter had himself obtained experimental values of the disruptive strength of air gaps up to 450 mm. by means of the sparks from a 50 cm. induction coil with 189,000 secondary turns and a closed magnetic circuit of about 30 sq. cms. cross section. By varying the number of primary turns he could obtain a wide range of transformation ratios. In Table VIB. are given as V_1, V_2, and V_3, Dr Walter's experimental values for transformation ratios of 1 : 1853; 1 : 1243 and 1 : 1068. $V_{obs.}$ is the mean of these three values, and $V_{calc.}$ are the corresponding values from his law in the form

$$V = 16{,}000 + 311\ d.$$

TABLE VIB.—WALTER'S OWN TESTS ON THE DISRUPTIVE STRENGTH OF AIR.

d in mm.	V_1	V_2	V_3	$V_{obs.}$	$V_{calc.}$	Δ
50	39,200	31,100	29,500	31,600	31,600	0·0
100	44,800	48,500	46,400	46,600	47,100	−1·1
150	62,800	63,600	63,000	63,100	62,700	+0·6
200	78,200	80,000	78,600	78,900	78,200	+0·9
250	93,200	96,700	94,000	94,600	93,800	+0·9
300	109,300	113,100	111,100	111,200	109,300	+1·7
350	123,900	126,800	124,900	125,100	124,900	+0·2
400	136,900	140,000	141,000	139,300	140,400	−0·8
450	152,300	155,300	...	153,800	156,000	−1·4

The values denoted by Δ are the percentage variations between V_{obs} and $V_{calc.}$ In these tests the electrodes were brass needles. The high-tension voltage was obtained by multiplying the readings

of the R.M.S. voltage on the low-tension side by the ratio of transformation. It was also observed that in these tests the ratio of maximum to R.M.S. voltage was quite constant for all spark lengths. The wave form was approximately a sine curve, and hence the maximum voltage may be obtained by multiplying $V_{obs.}$ by $\sqrt{2}$. It will be seen from Table VIB. that Dr Walter's formula gives excellent agreement with observed results for thicknesses of air from 50 to 450 millimetres. Dr Walter distinctly points out that his formula is unsuitable for small thicknesses of air, since when d approaches zero, so also must V.

Analysing Th. Gray's[1] tests on mica, Baur obtains the values in Table VII.

TABLE VII.—BAUR'S ANALYSIS OF GRAY'S TESTS ON DISRUPTIVE STRENGTH OF MICA. PLATE ELECTRODES AND ALTERNATING CURRENT. $c=58,000$ VOLTS.

Thickness in mm.	Disruptive Voltage.		Difference in per cent.
	Observed.	Calculated.	
0·1	11,500	12,500	−9
0·2	19,000	19,800	−4
0·5	37,000	36,600	+1
0·8	52,000	52,000	0
1·0	61,000	58,000	+5

For paraffin, Baur has taken some tests made by Weicker. The analysis is set forth in Table VIII.

TABLE VIII.—BAUR'S ANALYSIS OF WEICKER'S TESTS ON THE DISRUPTIVE STRENGTH OF PARAFFIN. PLATE ELECTRODES AND ALTERNATING CURRENT. $c=20,000$ VOLTS.

Thickness in mm.	Disruptive Voltage.		Difference in per cent.
	Observed.	Calculated.	
1	27,000	20,000	+35
2	39,000	32,000	+22
4	56,000	50,000	+12
6	68,000	66,000	+ 3
8	78,000	80,000	− 2
10	87,000	93,000	− 6
12	95,000	105,000	− 9
14	102,000	116,000	−12

[1] *Jour. Inst. Elec. Engrs.*, 1901, p. 641.

Weicker's original results on paraffin are plotted in fig. 27.

For hard porcelain, Baur obtained the results set forth in Table IX.

Baur closes his article by reverting to Walter's investigations (see p. 43), and points out that Walter reduced his tests to

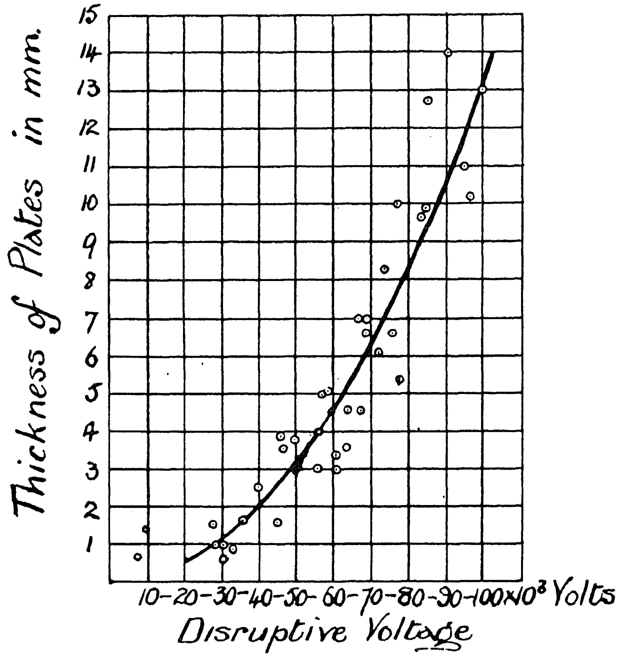


FIG. 27.—Weicker's Tests on the Disruptive Strength of Paraffin Plates.

TABLE IX.—BAUR'S COMPARISON OF RESULTS FOR HARD PORCELAIN. $c = 18{,}000$ VOLTS.

Thickness in mm.	Disruptive Voltage.		Difference in per cent.
	Observed.	Calculated.	
1	13,600	18,000	-24
2	25,200	28,700	-12
3	35,200	37,600	- 6
4	44,300	45,400	- 2
5	53,000	53,000	0
6	61,000	60,000	+ 2
7	69,000	66,000	+ 4
8	77,000	72,000	+ 7
9	84,000	79,000	+ 6
10	98,000	90,000	+10

equivalent spark lengths in air, and only inferred that the disruptive strength is directly proportional to the thickness, in virtue of the erroneous assumption that this is the case with air. As Baur claims to have shown that the disruptive strength of air is proportional to the two-thirds power of the thickness, he further claims that Walter's results are also a confirmation of the law that $V = cd^{\frac{2}{3}}$.

In his earlier article (1901), Baur applied his law to other cases, and gave the following interesting comparisons between the observed results and the results as calculated by his method.

The first comparison relates to cables insulated with impregnated jute. The insulations varied in thickness from 2 mm. to 24 mm. Employing in this case a value of 2200 volts for the electrical breaking strength, c, he obtained the results set forth in Table X.

TABLE X.—DISRUPTIVE STRENGTH OF IMPREGNATED JUTE.

Thickness of insulation, in mm. . . .	3	6	12	24
Observed disruptive strength, in volts .	4,800	7,200	12,000	19,000
Calculated disruptive strength, in volts .	4,600	7,200	11,400	18,300

The comparison shown in Table XI. refers to "calico impregnated with india-rubber of a thickness of 0·3 mm., of which different layers, to the number of ten, were tested for break-down between plane surfaces." Here, again, $c = 2200$ volts, and the curve forms a continuation of the jute cable curve.

TABLE XI.—DISRUPTIVE STRENGTH OF CALICO IMPREGNATED WITH INDIA-RUBBER.

Thickness of insulation, in mm. . . .	0·6	0·9	1·8	3·0
Observed disruptive strength, in volts .	1550	2000	3050	4400
Calculated disruptive strength, in volts .	1550	2050	3250	4560

For "Fuller board," $c = 19{,}000$ volts. The comparison is given in Table XII.

TABLE XII.—DISRUPTIVE STRENGTH OF "FULLER BOARD."

Thickness of insulation, in mm.	0·2	0·6	1·0	2·0	2·6
Observed disruptive strength, in volts	4,000	12,000	19,000	34,000	42,000
Calculated disruptive strength, in volts	6,400	13,500	19,000	30,000	38,000

For "empire cloth," $c = 12{,}500$ volts.

TABLE XIII.—DISRUPTIVE STRENGTH OF "EMPIRE CLOTH."

Thickness of insulation, in mm. . . .	0·2	0·6	1·0	2·0
Observed disruptive strength, in volts .	4,000	8,000	12,500	20,000
Calculated disruptive strength, in volts .	4,300	8,900	12,500	22,500

Baur finally gives a comparison for india-rubber insulated cable, for which he finds $c = 10,000$ volts.

TABLE XIV.—DISRUPTIVE STRENGTH OF INDIA-RUBBER INSULATED CABLE.

Thickness of insulation, in mm.	1	2	4	6	8	10
Observed disruptive strength, in volts . .	10,500	17,000	26,000	32,000	37,000	40,000
Calculated disruptive strength, in volts . .	10,000	16,000	25,000	33,000	40,000	46,000

O'Gorman,[1] in criticising the above data, expressed the opinion that for thicknesses exceeding 10 mm., and, for some materials, for much smaller thicknesses, the disruptive strength is proportional to the thickness.

Thus, for mica, the curve begins to straighten out before a thickness of 1 mm. is reached. He refers to the investigations of Trowbridge, who, in some elaborate experiments on the disruptive strength of very great thicknesses of air, found a straight-line law. O'Gorman states that "generally, as soon as we are dealing with high voltages, and therefore with thicknesses sufficiently great to cause the disappearance of what might provisionally be called "proximity resistance," a law simpler than Dr Baur's—namely, the straight-line law—appears to rule."

VII.—**Mechanical Properties.**—Insulating materials must be tested with respect to their mechanical properties. Some materials change their geometrical form under the influence of heat. Others become soft; others brittle. Many varnishes, notably shellac and copal varnishes, become reduced to powder under the influence of such continued vibration as occurs in dynamo-electric machinery.[2]

Dr Max von Recklinghausen [3] enumerates, as follows, the "factors

[1] "The Disruptive Strength of Insulating Materials," *Electrician*, September 20, 1901, p. 845.

[2] "Compounds made by the ordinary processes of varnish or paint manufacture are quickly disintegrated and reduced to a useless powder by the heat and vibration of dynamo-electric apparatus. Attempts have been made to check this by the introduction of slow-drying oils (such as corn oil and rapeseed oil) into gum varnishes, but with most disastrous results, as those materials form peculiarly active compounds of a hostile acid nature."—From a publication by the Massachusetts Chemical Co.

[3] "Insulating Materials a Field for the Chemist." A paper read by Dr Max von Recklinghausen before the American Electro-Chemical Society, April 16, 1903.

which may considerably influence the properties of insulating materials during work":—

I. Rise of temperature (going so far as melting or charring organic materials) due to—

A, current passing in virtue of the insulation resistance, with not enough chance to radiate the heat generated.

B, heat conducted into the insulating material from outside sources, such as the metallic conductor.

C, dielectric hysteresis, due to very frequent application and withdrawal of high electrical stress, such as high voltage alternating current, with not enough chance to radiate the heat generated.

II. Mechanical stress, resulting in change of shape or breaking.

III. Chemical action of, for instance, water, oil, ozone, nitrous fumes (which may be generated by brush discharges near by), gases and fumes developed by factory processes in the neighbourhood of the electrical apparatus.

One could well add to this list.

IV. Motor and generator insulations should not deteriorate under the influence of rapid successive heating and cooling.

VIII. **The Energy Losses in Insulating Materials.**—Vol. xix. of the *Trans. of the Am. Inst. of Elec. Engrs.* (1901) contains, at p. 1047, a most important paper by C. E. Skinner, entitled "Energy Loss in Commercial Insulating Materials when subjected to High Potential Stress."

Whereas prior published investigations on this subject have related far too exclusively to the insulating materials employed in condensers,[1] Skinner's paper treats of such losses in commercial apparatus, and these he terms "energy losses," to avoid entering into any theoretical discussion as to the existence of "dielectric hysteresis."

Variation of Temperature due to Variation of Stress.—From his investigations on this point, Skinner arrived at the following eight conclusions:—

[1] See Steinmetz on "Dielectric Hysteresis," in *Elec. Engr.* (N.Y.) for March 16, 1892.

"(1) With moderate stress, the temperature of the material rises rapidly at first, then more slowly, then becomes constant. The actual rise in the temperature for a given voltage depends upon the facility afforded to the material for dissipating its heat, and upon the temperature of the surrounding medium.[1]

"(2) As the stress is increased, a point is finally reached where the heat is developed at a greater rate than it can be carried away, and the temperature then rises until the material chars, and break-down results.

"(3) When material is not thoroughly dried, the temperature rises much more rapidly than in well-dried stock. The increased temperature cannot be accounted for by the increased I^2R loss due to lower insulation resistance. The heat generated tends to dry out the material, and the temperature may fall as the drying proceeds.

"(4) With a considerable area of material under test, the temperature of small portions frequently rises above that of the surrounding material to such an extent that, on examination, these portions are found to have become much discoloured, while the surrounding portions remain unchanged. This effect is especially noticeable with treated material not perfectly cured. The final break-down in such cases is invariably found to have occurred in one of the heated areas.

"(5) The final break-down in fibrous material usually results from the burning of the material, and not from mechanical rupture. When the e.m.f. applied is far above the dielectric strength of

[1] "As insulation heats up, it becomes much less able to withstand potential strains, and, further, the rate of generation of heat within the insulation itself becomes much greater. As a net result, if insulation under strain once reaches a sufficiently high temperature, it is practically certain to get still hotter, and ultimately break down. In other words, for continuous running it is necessary that the heat generated by the potential upon the dielectric be dissipated as fast as generated. In actual apparatus, the critical rise of temperature may be reached in as short a time as one-tenth of a second, perhaps, or in other cases, only after a long time, perhaps an hour. The latter time would be required only in large bodies of insulating material, *e.g.* in large capacity or high-tension apparatus.

"Solids and liquids practically have their breaking-down strength determined by this heat factor, rather than by their initial disruptive strength."—P. H. Thomas, "The Testing of Electrical Apparatus for Dielectric Strength," *Am. Inst. of Elec. Engrs.*, July 1, 1903.

the material, the break-down may be due to a mechanical rupture. If, however, the e.m.f. is sufficiently low, so that an appreciable time elapses before break-down occurs, the break-down is probably due to burning caused by the heat generated in the material. There may be some attendant chemical action, but this is thought to be a result, and not a cause, of the excessive heat. The lower the e.m.f. applied, the longer the time required to produce break-down under a given set of conditions.[1]

"(6) It follows from (5) that if the temperature is kept low, either by providing good ventilation or by artificial cooling, the stress required to cause break-down, in a time test, will be much greater than if the material is not so cooled.

"(7) The actual temperature measured in most fibrous materials before break-down occurred was usually 175° C. or more. In no case did a break-down occur directly at the point where temperature measurements were being made, and the temperature at the breaking-down point was probably higher than measured, especially as the rise in temperature seemed to be very rapid at the point of break-down just before this occurred.

"(8) With a given stress, the initial and surrounding temperature has much to do with the rise. This is due to the fact that the loss in the material increases rapidly with the temperature. For example, if the material and the surrounding air are at 20° C. and the stress applied is 20,000 volts, the rise in temperature will not be nearly so great as if the initial and surrounding temperature

[1] "The amount of heat generated within the body of a dielectric increases at least as fast as the square of the voltage. Further, this loss, with constant voltage, may be increased several times by an increase of 100° C. in temperature. This means that a strain of double potential continued for any length of time strains the solid insulating material far beyond any condition it will meet in service. Further, the ability to stand the strain will be determined rather by the facility for getting rid of the heat, which is usually of little consequence in commercial work, than by other features of the insulation more desirable for actual service; further, the hottest part of the insulation will be inside, so that the centre portion of the material may be badly charred, while the outer portion, the only part visible to the eye, has been kept cool and appears uninjured. This means that very serious injury to high-tension apparatus may be entirely beyond the possibility of detection until further developed by actual service." — P. H. Thomas, "The Testing of Electrical Apparatus for Dielectric Strength," *Am. Inst. of Elec. Engrs.*, July 1, 1903.

is at 80° C. Tests have shown that break-down frequently results, under the latter conditions, from a stress that would not injure the material under the former conditions."

Fig. 28 gives some of the characteristic curves obtained by Skinner for the rise of temperature in insulating material when subjected to high potential stress. "Curves A, B, and C were taken

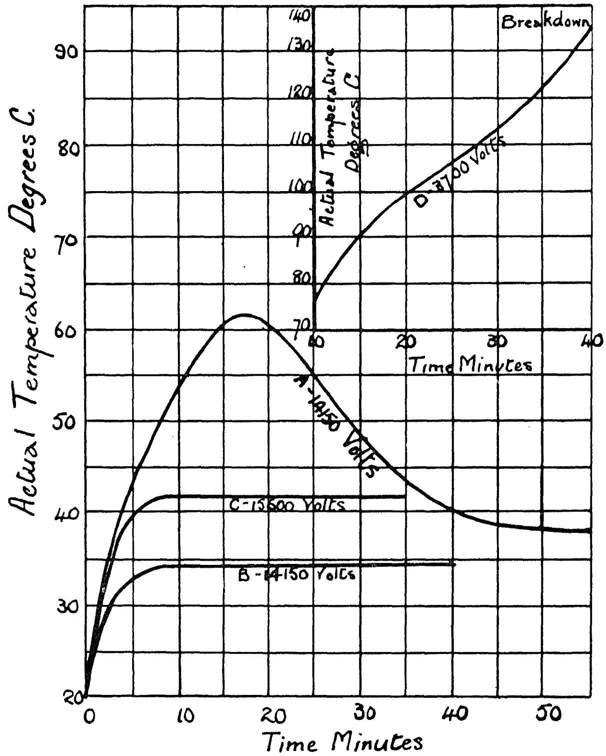


FIG. 28.—Skinner's Curves of Temperature Rise in Materials subjected to Dielectric Strains.

on a sample of untreated material which was quite porous and capable of absorbing moisture from the air. In this test, the material was well ventilated, so that any moisture could be quickly dissipated. The temperatures given are those actually measured, but probably do not represent the highest point reached in the material. Curve A shows the effect of moisture. The temperature rose very rapidly, reaching a maximum, then fell, and at last became stationary. Curve B shows the effect on the

same material after a very thorough drying. Curve C shows the increased temperature due to a slight increase in the stress.

"Curve D, at the upper right-hand corner of the figure, shows the rise in temperature in treated material when poorly ventilated, and the test continued until break-down resulted. Break-down in this particular test occurred at a point about 4 inches from the thermo-junction, when the measured temperature reached 135° C.

"It is probable that the temperature measured was considerably lower than that reached at the point of break-down. The temperature of the surrounding air in this test was kept at 80° C. This curve shows the tendency of the temperature to become constant, but at a point slightly over 100° C. the loss becomes so great that the heat cannot be dissipated as fast as generated, hence the change in direction of the curve, and final break-down. In numerous tests, the material was found to be badly charred on the interior, without break-down having resulted. The curves shown are characteristic, and are of the same form as many others that have been taken."

Variation of Loss due to Variation of Temperature.—Skinner's investigation of the variation of loss due to variation of temperature led to the following seven conclusions:—

"(1) The energy loss in fibrous material increases with temperature, the rate of increase in the loss being greater than the rate of increase in the temperature.

"(2) The rate of increase depends upon the kind of material, and on its condition with respect to dryness, etc.

"(3) The local heating found in a mass of poorly ventilated material is due to a greater initial loss in one portion causing increased heating, this in turn causing greater loss, etc., until the temperature finally reaches a point at which charring and break-down result.

"(4) The curves of fig. 29 show that the rate of increase of loss is greater at high than at low temperatures, therefore giving the reason for the greater rise in temperature with a given stress when the initial temperature is high than when it is low.

"(5) That the loss increases very rapidly indeed when the temperature approaches the charring temperature of the material.

"(6) Losses as great as 0·3 watts per cubic centimetre have been measured in material before serious injury due to charring resulted. A loss considerably less than this will, however, char the material in time, unless special means are taken to dissipate the heat generated.

"(7) It follows from considerations of rise of temperature due to

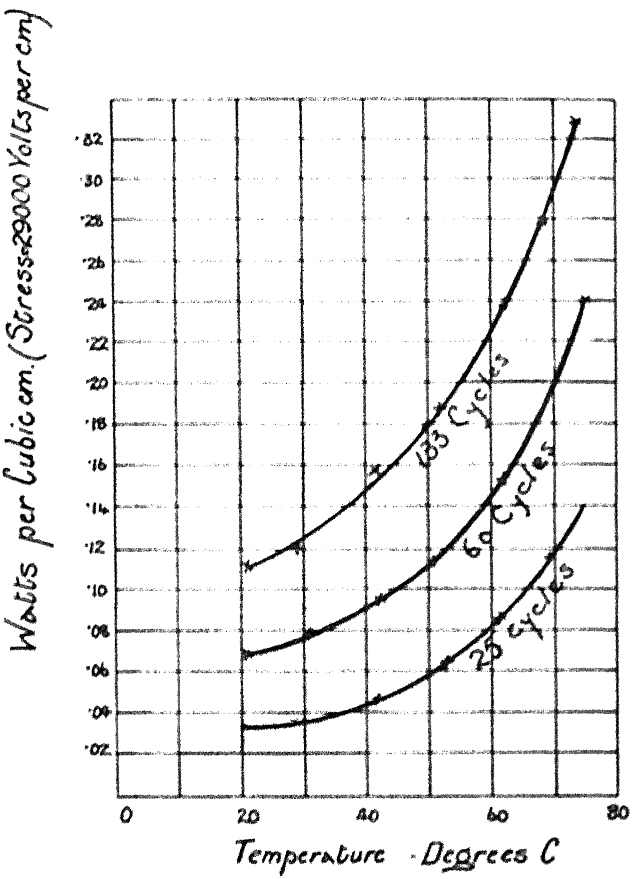


FIG. 29.—Skinner's Investigation of the Variation of the Energy Loss in Insulating Materials, with the Frequency.

increased stress, and increase in loss due to increase in temperature, that *a long-continued test at high stress may seriously injure the insulation of a piece of apparatus without this being made apparent by the test.* This has often been spoken of as 'straining the insulation,' for want of a better term, the idea being that this was in some way analogous to the straining of a piece of metal

beyond its elastic limit. It is probable that this 'straining' is always due to charring."

The curves of fig. 29, on a particular sample, are representative of the general way in which the loss in the insulating material investigated by Skinner at the Westinghouse Electric Co.'s Works at Pittsburg, U.S.A., varies with the temperature and frequency. In this investigation, one great difficulty related to the inaccuracy of measurement of energy losses at such low-power factors as 0·1 and less.

"*Variation of Loss due to Variation of Voltage.*—When tests on this point were made at constant temperature, the results confirmed the following law, announced in 1892 by Steinmetz:—'The energy consumed by the dielectric medium under alternating electrostatic strain is directly proportional to the square of the intensity of the electrostatic strain.' Thus the loss is due to conduction through the ohmic resistance of the dielectric.

"With regard to the variation of the loss with the voltage, the temperature varying due to the loss itself, it follows from the preceding conclusions: (1*st*) that under the usual conditions of high potential stress, the loss will increase more rapidly than the square of the voltage, because the temperature increases at the same time; (2*nd*) that the rate of this increase will depend on the facility with which the material can get rid of its heat, and on the length of time the material is subjected to each successive stress in carrying out the test; (3*rd*) that it will also depend on the initial temperature of the material and the temperature of the surrounding medium."

The paper closes with a description of some tests of the energy losses in the armature insulation made on the Manhattan Railway Co.'s 5000 k.w., 11,000 terminal volt, star-connected, 25-cycle, 3-phase Westinghouse alternators. The tests were made on two of these machines after installation. The results are plotted in the curves A and B of fig. 30, the two curves relating to the results on the two different machines. For curve A, the temperature of the windings was about 21° C; for curve B, about 31° C. The amount of insulating material per armature was 320,000 cubic centimetres; so that at 25,000 volts the maximum loss amounted to 0·021 watts per cubic centimetre. During the tests,

the total loss was insufficient to cause appreciable heating, and the measurements, although in one case continued over 30 minutes at 25,000 volts, showed no variation in the loss.[1]

IX. The Influence of Brush Discharge and Surface Leakage.—Brush discharge and surface leakage are, of course,

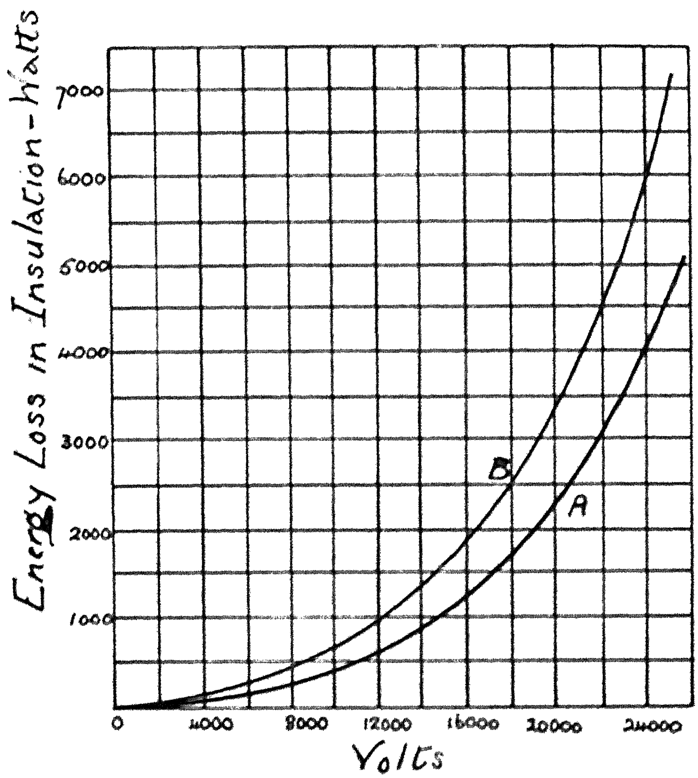


Fig. 30. Skinner's Tests of the Energy Loss in two 5000 K.W., 11,000 Volt, Westinghouse Three-Phase Alternators, installed in the Manhattan Railway Co.'s Power House.

greatly affected by the conditions of the atmosphere; hardly less, however, by the character of the insulating material. Continued discharge at one point may char and deteriorate the insulation, and it has been pointed out that the discharge may then continue at a lower voltage. P. H. Thomas has referred to the fact that such discharges "will occur even under oil, and, like the internal

[1] The authors wish to express their appreciation of Mr Skinner's courtesy in permitting them to include so large a portion of this exceptionally valuable paper.

heat, will not be visible to the eye until in a very advanced stage."[1] Brush discharges also take place when air holes are present, and when, in consequence, the voltage gradient is high. While the presence of surface leakage introduces uncertainty as to the precise puncturing point, it may in practice sometimes be of actual advantage by distributing and relieving the stress.

X. Abrupt Charge and Discharge Phenomena. In the paper above referred to, Mr P. H. Thomas has referred to another very important phenomenon, which he describes as follows:

"When a coil is charged to a high potential and one end is suddenly discharged, there is a strain equal as a maximum to the full value of the discharge voltage, tending to cause the charge upon the turns of the coil to jump to the terminal through the insulation between the turns, rather than pass around these turns. Since the total discharge voltage may be the abnormal voltage at which the apparatus is being tested, and since this abnormal strain may be concentrated on a portion of one coil, where many coils are used to withstand the normal voltage of the circuit, it is evident that certain turns of the coil (which lie next to the terminal which is being discharged) will receive excessive strain. The condition which is essential to produce this concentration is that the discharge of the terminal of the coil shall be extremely sudden. This can usually occur only when the terminal is discharged by a spark close to the terminal itself, electrically speaking, *e.g.* any accidental or other discharge between the wires used in applying the test, or in the apparatus itself, will tend to puncture the insulation between turns at certain points within the winding. Such injury will oftentimes not be discovered, as the apparatus being tested is not in a condition to show a short circuit when it is not connected to a generator. This danger is very serious with extremely high voltages. Apparatus may be protected against this strain by the use of choke coils or high resistances, or static interrupters in the leads of the apparatus to be protected, provided no discharge occurs nearer the apparatus than the protective device. *In this connection it should be noted that if the spark gap is used as an auxiliary to measure the*

[1] "The Testing of Electrical Apparatus for Dielectric Strength," *Trans. Am. Inst. of Elect. Engrs.*, July 1, 1903.

potential of the test, satisfactory means must be used to prevent a discharge on the spark gap from causing injury to the apparatus being tested.

"The emphasis placed on this particular phenomenon is not for theoretical reasons only, but because in a number of cases serious injury has resulted to apparatus therefrom. Furthermore, such conditions have been reproduced for purposes of investigation." This is a most important point. Attention has also been directed to it by Duddell in 1902 in a contribution to the *Proceedings of the Institution of Electrical Engineers.* Duddell showed that by suddenly breaking any circuit that contained self-induction and capacity, there was very likely to be an enormous voltage rise.

Mr M. B. Field,[1] referring to a still earlier paper by Thomas ("Static Strains in High-Tension Circuits and the Protection of Apparatus," *Trans. Am. Inst. of Elec. Engrs.*, vol. xix., 1902, p. 213), thus interestingly describes related phenomena:

"I will briefly explain here the nature of the so-called 'static strains,' of which the above-referred-to paper treats.

"In fig. 31, S represents a source of high potential (V). A B, a circuit or line of any nature at zero potential.

"At the instant before closing the switch, the potential is represented by the full black line in fig. 32. Now, on closing the switch the line A B cannot, as we have seen, be instantly raised to the potential V; in fact, at the moment of closing, the potential (assuming no spark occurs) all along the circuit would likewise be represented by the full line in fig. 32. Instantly, however, the charge in the portion of the system S T begins to distribute itself over the whole system from S to B, the first effect being a tendency for the electrostatic charges in the neighbourhood of the switch to equalise themselves, resulting in a moderation of the steepness of the potential line, as shown dotted in fig. 32.

"The potential 'front' will then travel along the system to B, becoming modified as it proceeds, depending on the constants of the line and circuit. The question is, What is the potential gradient at all parts of the circuit as this potential 'front' reaches them? It is a question of vast moment. Everyone who has

[1] *Proc. Inst. Elec. Engrs.*, vol. xxxii., 1903, pp. 682–694.

worked much with high-tension motors and transformers will have experienced difficulty owing to the short-circuiting of turns and layers in a most curious way. I have seen the winding stripped off high-tension motors, the insulation of which was punctured with innumerable pinholes.[1] The normal voltage between turns is a perfectly definite quantity, and accounts in no way for the puncturing. But it is clear that if a potential front with a steep potential gradient traverses the winding, the potential difference between neighbouring windings or layers may be very

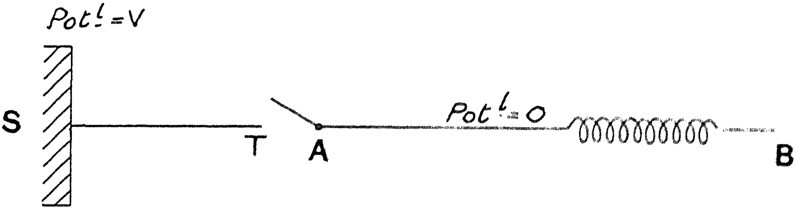


FIG. 31.

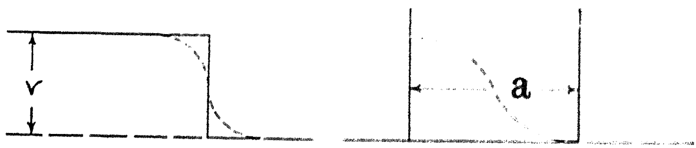


FIG. 32.

Field's Explanation of "Potential Fronts" and "Potential Gradients."

excessive in comparison with that after the normal steady state has been reached. For example, if the distance *a* in fig. 32 represents the length of two layers, it would be possible to have momentarily the full potential of the circuit across these layers.

"On switching a high-tension motor on to a circuit, both poles cannot be closed simultaneously. On closing the first pole we have the state of things already discussed, and represented in fig. 32. The potential front, on reaching the dead end of the circuit, is reflected back; there occurs, one may almost say, a 'splash' of potential, possibly analogous to the splash caused by a sea wave on reaching a boundary-wall, and similar to the reflected waves we have already discussed.

[1] This has been frequently observed by the Authors.

"The same thing will occur on closing the second pole of the circuit, only in this case the height of the potential front will be twice what it was in the preceding case.

"It is, of course, difficult to say whether the strain on the insulation is greater in this case than in the preceding; in general, we may say that if the front extends over a distance of more than two layers of the winding, the strain will be determined by the potential gradient.

"These potential fronts may be created at any point of the circuit by suddenly altering the potential at that point, *e.g.* by short-circuiting, grounding, and the like.

"This is a subject that will amply repay anyone who will undertake a careful research."

On account of phenomena of this sort, it is important, in testing large machines, to disconnect the circuit into as many independent groups of coils as practicable, and to test each separately.

NOTE.—While this treatise was going through the press, contributions from Weicker, Baur and Grob, dealing with the points raised by Walter in the article referred to on p. 51, have appeared in the *Elek. Zeit.* for Nov. 3 and 10, 1904 (Heft 44, p. 947, "Das Durchschlagsgesetz für atmosphärische Luft," W. Weicker, and "Das Gesetz der elektrischen Durchschläge," C. Baur; Heft 45, p. 951, "Über das elektrische Durchschlagsgesetz für atmosphärische Luft," Hugo Grob).

Also, still later :—"Die Schlagweiten in gasförmigen, flüssigen und festen Körper," W. Volge, *Elek. Zeit.*, Dec. 8, 1904, Heft 45, p. 1033.

CHAPTER III

THE INSULATION ON "MAGNET WIRES" EMPLOYED IN ARMATURE AND FIELD WINDINGS

A VERY large percentage of all the copper employed in electrical apparatus is in the form of so-called "magnet wire." This is generally of circular cross section, and in most cases is lightly insulated with cotton (and sometimes silk), applied in the form of a spun yarn.[1]

Dr Perrine describes such coverings as "simply intended to separate wires by a space, leakage being prevented both by the properties of the covering and by the insulating properties of the air retained within the space." It is often found desirable in armature and field coils to remove the air from this space and replace it with some insulating varnish or other material, the loose fibrous material merely serving to maintain a suitable safe distance between neighbouring conductors, and to serve as a skeleton for the varnish or other impregnating material.

The yarn is "closely and uniformly applied to the wire in such a manner that the conductor will maintain its position relative to all other conductors without regard to mechanical strains applied to it." Dr Perrine defines the characteristics essential to a satisfactory magnet wire to be: "The covering shall of itself, when dry, be of high insulating power; it shall be applied to the wire in such a uniform manner as to allow the wire to be placed in a

[1] According to Perrine (*Conductors for Electrical Distribution*, chapter v.), "spun yarn is distinguished from thread by its comparatively loose twist and by the fibres being all twisted in the same direction, thread being composed of a number of yarns so twisted that it will maintain its cylindrical shape even when a considerable pressure is applied."

definite space; the covering shall be sufficiently flexible to withstand a considerable amount of bending and abrasion."[1]

The use of silk-covered wire is sometimes preferable, notwithstanding its higher cost, owing to the greater economy in space. Dr Perrine states that whereas the thickness of a single layer of silk[2] need not exceed 1 mil. (0·025 mm.), the smallest cotton yarn cannot be lain in a layer less than 2·25 mils. (0·057 mm.) in depth.[3]

"In the case of silk, a greater thickness is obtained by employing more than a single winding, laid on in such a direction that the yarn from the first covering crosses the yarn from the second covering in an opposite spiral.

"With the cotton yarn we may increase the thickness of the insulation, as with silk, by increasing the number of layers; but it has also been found practicable to use yarns of a greater diameter, so that a single covering may be laid, up to a thickness as great as 5 mils. Double winds are consequently used in cotton-insulated wire for the purpose of obtaining insulation which will be perfectly continuous, and for strength rather than for obtaining a great amount of thickness, which, as already explained, could be produced by increasing the size of the yarn, though in general it is found to be inadvisable to use a yarn giving a greater thickness than 5 mils., on account of the fact that the thicker yarns are soft in character, and do not result in a covering which will withstand mechanical strains. The manufacture of this class of insulated wire requires the greatest care and the most perfect machinery, for the reason that the finished product must be as nearly as possible uniform in size, completely covered, and the surface so hard that the wire when placed will not change its position. In order to obtain these qualities, the

[1] "While other fibrous yarns might be used to obtain these qualities, it is found that finely spun silk and cotton are the only materials available."—Perrine, *Conductors for Electrical Distribution*, p. 83.

[2] For such purposes "the silk used is spun in such a manner that, while free from ends, the twist of the thread shall be so loose as to allow the covering machines to spread it in an even and thin layer over the surface of the wire; the machine winding it upon the wire in a spiral of an exceedingly short pitch, amounting in general to not more than $\frac{1}{100}$th of an inch (0·25 mm.) per turn."—Perrine, *Conductors for Electrical Distribution*, p. 83.

[3] One layer of silk next the wire and an outer covering of cotton is sometimes a useful compromise.

wire must be drawn through the machine at a definite rate in relation to the speed of the spools containing the yarn. Where more than one covering is applied at the same time, the drawing-out mechanism and the different sets of winding spools must all be so connected that there will not be any possibility of mechanical slip between the various parts. The yarn itself must be laid on under a considerable amount of tension, which cannot be applied to a single strand of yarn, but only to many strands laid together, the tension being obtained partially by a spring retarding the spool from which the yarn is unwinding, and partially by the fact that the spools themselves revolve at a very high rate of speed as they wind the yarn on to the wire. All of these operations are performed so accurately in modern wire-winding machines that it is possible for manufacturers to guarantee absolute continuity of insulation, and that the diameter of the insulated wire shall not vary more than 1 mil. from the standard size.

"In use, magnet wire, when perfectly made, forms a satisfactory insulation for most purposes without the application of any additional insulating material; but where it is subject to considerable difference of potential between the different wires, and where it has to stand severe mechanical strains, it is more generally the custom to saturate the insulation either with shellac, supplied in solution, or with asphaltum varnish, or to immerse the coil in an insulating oil. These additional precautions are mainly for the purpose of preventing any absorption of moisture by the wire after it has been thoroughly dried, than for increasing the insulating power of the dried cotton, the value of the material used depending largely upon its power of excluding moisture under all conditions." [1]

In Farrington's Franklin Institute paper,[2] the author, in discussing the subject of the impregnation of the cotton coverings of copper wire with insulating compounds, defined the three chief defects of cotton as insulation to be as follows:—

"The first defect of cotton is the fact that it cannot be spun to a commercial profit unless it carries from 5 per cent. to 15 per

[1] Acknowledgment is due to Dr Perrine for kindly granting us permission to make the above copious extracts from his work entitled *Conductors for Electrical Distribution.*

[2] "Defective Machine Insulation," March 12, 1903.

cent. of water, but at the same time our attention should not lose the fact that this water does not interfere with the average insulation value of cotton covering, as indicated by mere laboratory tests. The trouble which the water makes is accomplished when it vaporises under the heat of the machine, or when it travels from the core out through the coil under the influence of rotary

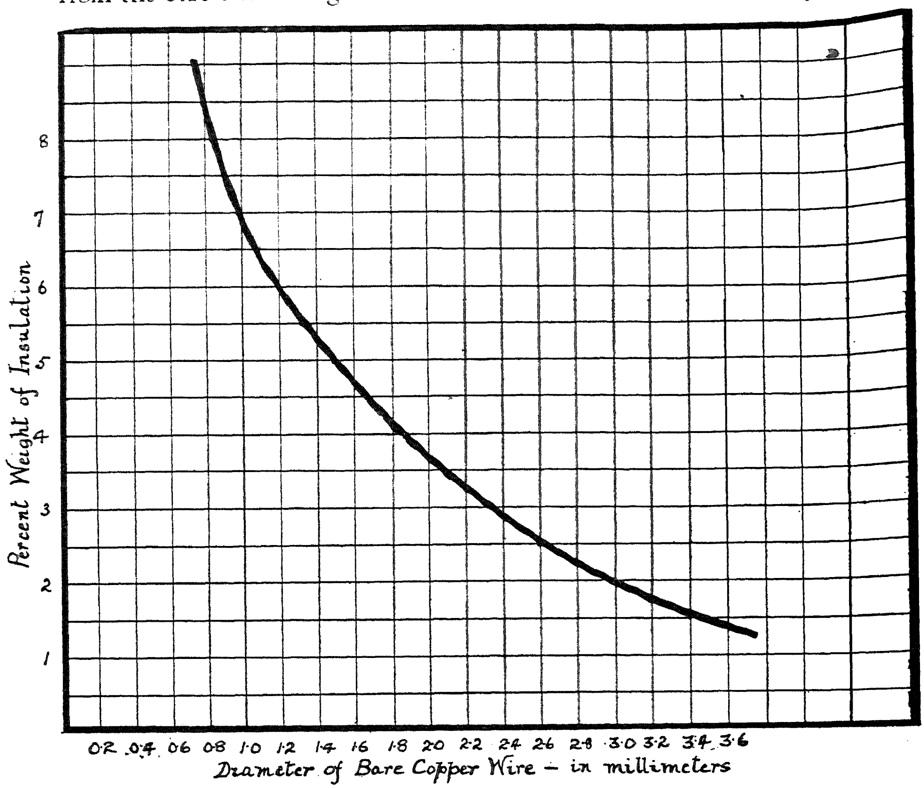


FIG. 33.—Curve showing the Percentage by which the Average Commercial Double Cotton Covering increases the Weight of Copper Magnet Wire.

motion, leaving innumerable passages and openings where the electric current may follow.

"Another material defect of cotton is the ease with which it becomes carbonised; but it is only fair to say that the carbonisation of cotton covering is largely offset by the resistance gained from the expulsion of moisture as an armature becomes dried and seasoned.[1]

[1] There are now on the market a number of so-called heat-dissipating varnishes, some of which also preserve and toughen cotton coverings. See Chapter IX.

"The third defect of cotton is the acid which it carries, and which assists its impregnation with copper oxide."

The Weight of Insulation on the Magnet Wire.—While this varies to a considerable extent, chiefly in accordance with the stipulated thickness and number of coverings, the curve in fig. 33 gives approximate average data for the percentage increase in weight due to a double covering of cotton. This increase is important to keep in mind when ordering quantities for manufacturing into spools, since the weight stated by the designer to be required for a given design is generally derived from standard wire tables, and refers to the weight of the copper alone. The curve should also afford a sufficiently good basis for estimating the weights of single cotton-covered and of silk-covered wires, since, for a given gauge, the percentage increase in weight would be closely proportional to the thickness of the insulation.

As to the attainable degree of thinness of the silk and cotton coverings, Dr Perrine's estimate has been given above.

A prominent concern, manufacturing "magnet wires," has issued a set of wire tables, from which Table XV. has been compiled.

TABLE XV.—SHOWING THICKNESS OF COTTON COVERINGS ON STANDARD ARMATURE AND MAGNET WIRES.

Double Lapping (fine).

British Measure.

All sizes to No. 20 S.W.G.	add 6 mils.
Nos. 19 and 18	,, 8 ,,
Nos. 17 to 13	,, 10 ,,
No. 12 and larger	,, 12 ,,

Metric System.

All sizes to 0·9 mm. dia.	add 0·15 mm.
From 1·0 mm. dia. to 1·2 mm. dia.	,, 0·20 ,,
From 1·4 mm. dia. to 2·3 mm. dia.	,, 0·25 ,,
For 2·6 mm. dia. and larger	,, 0·30 ,,

Double Lapping (ordinary).

British Measure.

All sizes to No. 18	add 10 mils.
Nos. 17 to 13	,, 12 ,,
Nos. 12 and larger	,, 14 ,,

Metric System.

All sizes to 1·2 mm. dia.	add 0·25 mm.
From 1·4 mm. dia. to 2·3 mm. dia.	,, 0·30 ,,
For 2·6 mm. dia. and larger dia.	,, 0·35 ,,

A fine close braiding is generally 5 to 8 mils. (0·13 mm. to 0·20 mm.) thicker than the ordinary double lapping.

Manufacturer's Note.—Thickness of covering may be varied to a large extent, to suit the user's requirements.

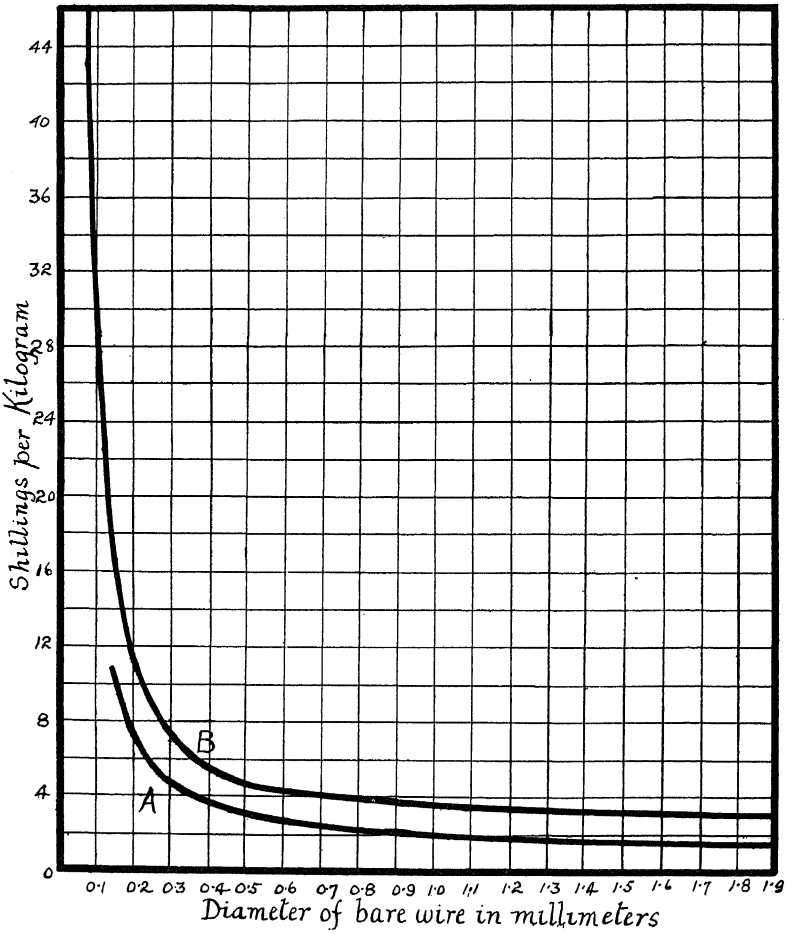


FIG. 34.—Cost per Kilogram of Single-Covered Magnet Wires. Curve A, covering is cotton; Curve B, covering is silk.

Most manufacturers of electrical apparatus specify and obtain far thinner cotton coverings. A standard to be recommended as imposing no unreasonable difficulties on the wire-manufacturer, is that employed in Table XVA.

Gauge Name.	Gauge No.
S.W.G.	7/0
..	..
S.W.G.	6/0
B. & S	000
B.W.G.	000
S.W.G.	5/0
B.W.G.	000
B. & S.	000
S.W.G.	4/0
..	..
B.W.G.	00
S.W.G.	000
B. & S.	00
..	..
S.W.G.	00
B.W.G.	0
B. & S.	0
S.W.G.	0
..	..
S.W.G	1
B.W.G.	1
B. & S.	1
B.W G.	2
S.W.G.	2
B.W.G.	3
B. & S.	2
S.W.G.	3
B.W.G.	4
..	..
S.W.G.	4
B. & S.	3
B.W.G.	5
S.W.G.	5
B. & S.	4
B.W.G.	6
..	..
S.W.G.	6
B. & S.	5
B.W.G.	7
S.W.G.	7
B.W.G	8
B. & S.	6
S.W.G.	8
..	..
B.W.G.	9
B. & S.	7
S.W.G.	9
B.W.G.	10

Gauge No.	Diameter. Bare. Millimetres.	Bare. Inches.	S.C.C. Mm.	S.C.C. Ins.	D.C.C. Mm.	D.C.C. Ins.	T.C.C. Mm.	T.C.C. Ins.
24	·5100	·0201	·610	·024	·710	·028	·812	·032
25	·5080	·0200	·610	·024	·710	·028	·812	·032
25	·5080	·0200	·610	·024	·710	·028	·812	·032
..	·5	·0197	·602	·024	·710	·028	·790	·031
26	·4570	·0180	·559	·022	·660	·026	·762	·030
26	·4570	·0180	·559	·022	·660	·026	·762	·030
25	·4550	·0179	·559	·022	·660	·026	·762	·030
27	·4160	·0164	·508	·020	·610	·024	..	..
27	·4060	·0160	·508	·020	·610	·024	..	..
26	·4040	·0159	·508	·020	·610	·024	..	..
..	·4	·0157	·504	·020	·610	·024	..	..
28	·3760	·0148	·483	·019	·585	·023	..	..
27	·3605	·0142	·457	·018	·559	·022	..	..
28	·3560	·0140	·457	·018	·559	·022	..	..
29	·3460	·0136	·457	·018	·559	·022	..	..
29	·3300	·0130	·432	·017	·533	·021	..	..
28	·3200	·0126	·432	·017	·533	·021	..	..
30	·3150	·0124	·432	·017	·533	·021	..	..
30	·3050	·0120	·417	·016	·508	·020	..	..
29	·3	·0118	·381	·015	·508	·020	..	..
31	·2950	·0116	·407	·016	·508	·020	..	..
32	·2740	·0109	·381	·015	·482	·019	..	..
30	·2540	·0100	·356	·014	·457	·018	..	..
31	·2540	·0100	·356	·014	·457	·018	..	.
33	·2540	·0100	·356	·014	·457	·018	..	..
34	·2340	·00920	·330	·013	..	..	..	..
32	·2280	·00900	·318	·0125	..	..	..	..
31	·2270	·00893	·318	·0125	..	..	..	..
35	·2138	·00840	·305	·012	..	..	..	..
33	·2030	·00800	·292	·0115	..	..	..	..
32	·2020	·00795	·292	·0115	..	..	..	..
..	·2	·00788	·290	·0114	..	..	..	..
36	·1930	·00760	·280	·0110	..	..	..	..
33	·1800	·00708	·266	·0105	..	..	..	..
34	·1780	·00700	·254	·0100	..	..	..	..
37	·1730	·00680	·254	·0100	..	..	..	..
34	·1600	·00631	·249	·0098	..	..	..	..
38	·1525	·00600	·241	·0095	..	..	..	..
35	·1430	·00562	·218	·0086	..	..	..	..
39	·1320	·00520	·216	·0085	·280	·011	..	..
36	·1270	·00500	·203	·0080	·280	·011	..	..
35	·1270	·00500	·203	·0080	·280	·011	..	..
40	·1220	·00480	·203	·0080	..	..	..	..
37	·1130	·00445	·190	·0075	..	..	..	..
41	·1120	·00440	·190	·0075	..	..	..	..
36	·1016	·00400	·177	·0070	..	..	..	..
42	·1016	·00400	·177	·0070	..	..	..	..
38	·1010	·00397	..	..	..	..	..	..
..	·1	·00393	..	..	..	..	..	..
43	·0915	·00360	..	.	..	..	..	..
39	·0895	·00353	..	..	..	..	..	..
44	·0813	·00320	..	..	..	..	..	..
40	·0800	·00315	..	..	..	..	..	..
45	·0711	·00280	..	..	..	..	..	..
46	·0610	·00240	..	..	..	..	..	..
47	·0509	·00200	..	..	..	..	..	..
48	·0406	·00160	..	..	..	..	..	..
49	·0305	·00120	..	..	..	..	..	..
50	·0254	·00100	..	..	..	..	..	..

[*To face p.* 74.

Cotton coverings still considerably thinner may generally be obtained, but at an increased cost.

Table XVI and the curves in figs. 34 and 35 give a rough idea of the relative market prices of plain magnet wires with single

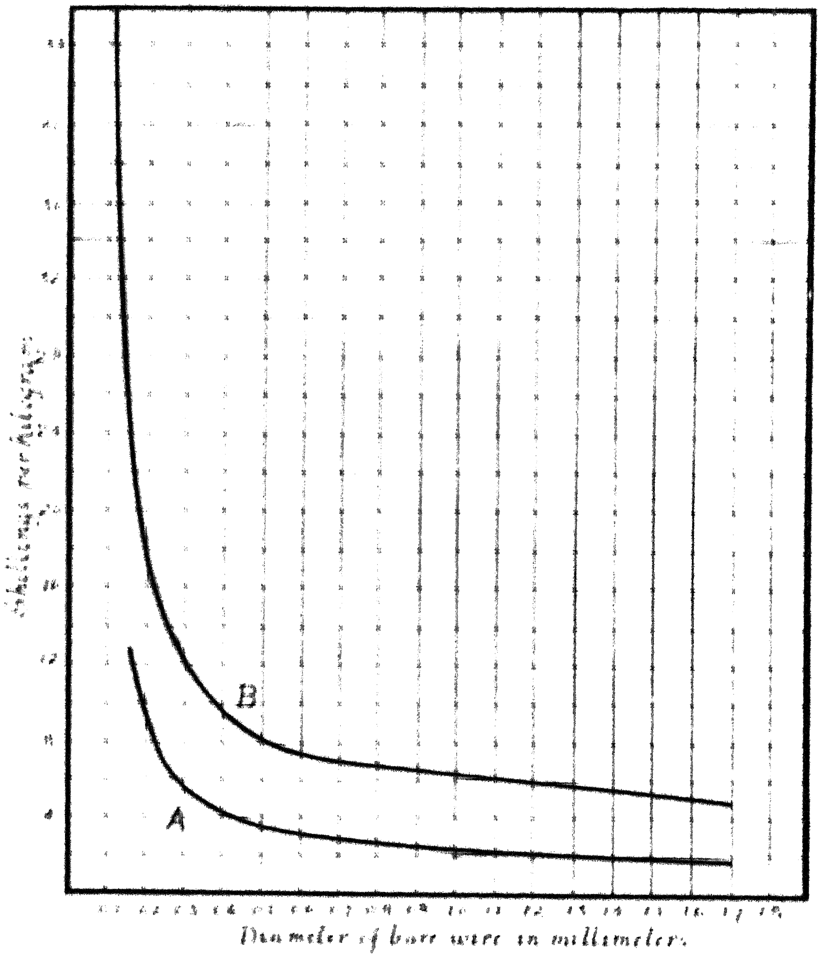


Fig. 35. Cost per Kilogram of Double-Covered Magnet Wires, i.e. wound with two laps in reverse direction. Curve A, covering in cotton; Curve B, covering in silk.

and double silk and cotton coverings, the thickness of the coverings corresponding to the values in Table XV.

It is seen from the table that "double silk" and "single cotton" are not much different as regards total thickness of

TABLE XVI.—COST OF MAGNET WIRES WITH SINGLE AND DOUBLE SILK AND COTTON COVERINGS.

S.W.G.	Bare Diam. in mm.	Cost in Shillings per Kilogram (expressed decimally).			
		Silk-covered.		Cotton-covered.	
		One Lap of Silk.	Two Laps of Silk in reverse direction.	One Lap of Cotton.	Two Laps of Cotton in reverse direction.
8	4·06	2·88	4·24	1·52	1·64
10	3·25	2·88	4·24	1·52	1·64
12	2·64	3·04	4·56	1·52	1·64
14	2·03	3·04	4·56	1·52	1·64
16	1·63	3·16	4·96	1·64	1·80
18	1·22	3·32	5·76	1·64	1·92
19	1·016	3·56	6·20	1·92	2·20
20	0·914	3·72	6·60	2·20	2·48
21	0·813	3·84	6·88	2·32	2·60
22	0·711	4·12	7·00	2·48	2·76
23	0·610	4·12	7·00	2·48	2·76
24	0·560	4·40	7·84	2·88	3·32
25	0·508	4·40	7·84	2·88	3·32
26	0·457	4·56	8·24	3·32	3·84
27	0·417	4·96	9·08	3·56	4·12
28	0·376	5·76	9·92	3·84	4·40
30	0·315	7·00	11·16	4·40	4·96
32	0·274	7·84	13·20	4·96	6·04
34	0·234	9·08	14·84	5·52	7·40
35	0·213	10·72	16·08	6·20	8·68
36	0·195	11·56	17·34	7·44	9·92
38	0·152	16·48	23·08	9·64	13·20
39	0·132	21·44	31·40		
40	0·122	23·08	37·99		
42	0·1016	28·04	46·20		
44	0·0813	42·88	66·00		
46	0·0610	59·40	82·40		
47	0·0508	74·40	123·80		

insulation. So far as relates to the insulating properties of silk and cotton, there is probably little or nothing to choose, for a given thickness, but the use of two layers gives additional security, through the decreased danger from mechanical imperfection in any layer; and cases arise where it is distinctly preferable to use double silk-covered wire in place of single cotton-covered wire, in spite of the far higher cost per kilogram. (Compare curve B of fig. 35 with curve A of fig. 34.)

Replacing double cotton-covered with double silk-covered wire, leads, especially in the case of armature windings, to great

TABLE XVII.—ROUGH AVERAGE VALUES FOR THE INSULATION THICKNESSES OF SILK- AND COTTON-COVERED MAGNET WIRES.

	Thickness of Insulation.	
	Millimetres.	Millimetres.
Single Silk Covering . . .	1·0 to 2·0	·025 to 0·50
Single Cotton Covering . .	3·0 „ 3·5	·076 „ ·089
Double Silk Covering . . .	2·0 „ 3·0	·050 „ ·076
Double Cotton Covering . .	6·0 „ 7·0	·15 „ ·18

economies in space where wires of small diameter come into question, and is often the correct thing to do. This is made much more apparent in the chapter relating to the "space factor." The increased cost is seen by comparing curves B and A of fig. 35. For wires with a bare diameter of 0·3 mm. the cost per kilogram is approximately doubled, but it must be remembered that of each kilogram bought at this price a greater percentage is copper in the case of the silk-covered wire; thus, whereas in the case of the double cotton-covered conductor the insulation would constitute, as seen from fig. 33, some 15 per cent. of the total weight, the insulation would not constitute over 7 per cent. of the total weight in the case of double silk-covered wire.

In the case of still finer wires, where, as seen from fig. 34, the difference in cost is much less marked, this difference in the percentage of insulation is far greater, so that the use of silk-covered wire becomes rapidly more justified the finer the bare wire.

One difficulty encountered in the employment of silk-covered wires is that the insulating varnishes customarily used, assimilate well with cotton, having been more or less unconsciously developed with this end in view. It has been maintained that the use of silk raises a new condition radically affecting the choice of insulating varnishes, and requiring independent development to suit the new conditions.

CHAPTER IV

STEINMETZ' INVESTIGATIONS ON THE DISRUPTIVE STRENGTH OF INSULATING MATERIALS

THE first fairly comprehensive investigation on modern insulating materials, which reveals a clear appreciation of the nature of the data required in the design of the insulation for dynamo-electric

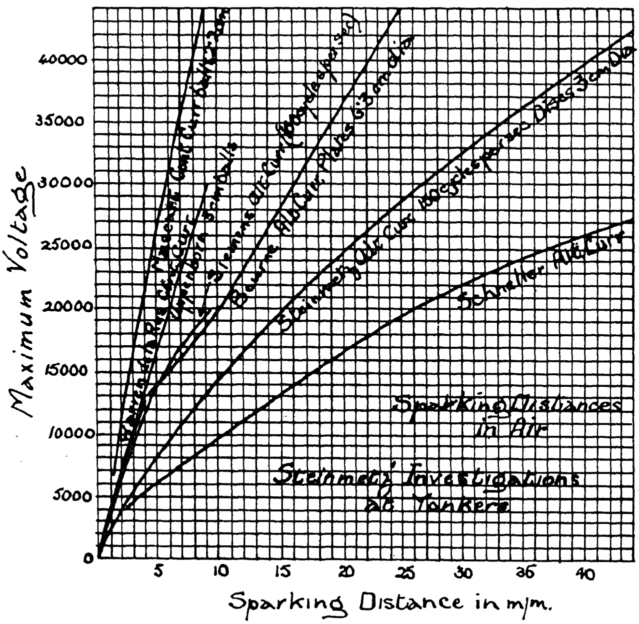


FIG. 36.

machinery, is that which was carried out by Steinmetz at the Eickemeyer Laboratory, at Yonkers, New York. The results are set forth in a paper entitled "Notes on the Disruptive Strength of

Dielectrics," contributed by Steinmetz in 1893 to the Transactions of the Amer. Inst. of Elec. Engrs. (see page 64 of vol. x. of the *Trans. Amer. Inst. Elec. Engrs.*). The results of Steinmetz' original tests on the disruptive strength of air, and of the tests of other investigators as compiled by him, are shown in the curves of fig. 36. The great differences in the results obtained by various experimenters are commented upon by Steinmetz as follows :—

"Conceding even a large margin of uncertainty for the older tests made with electrostatic machines, and leaving out of con-

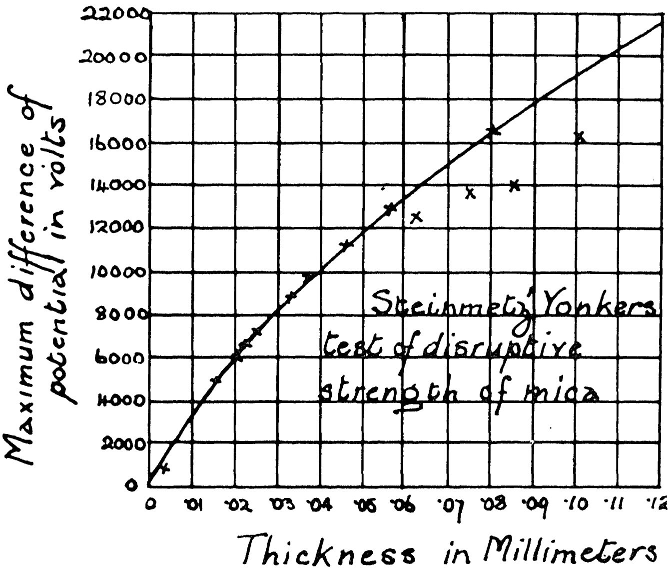


FIG. 37.

sideration those tests where not sufficient explanation was given to permit critical discussion of the method, the discrepancies are still too large to permit of explanation by errors of observation. The different curves differ considerably in shape; the best and most reliable values, however, fairly well point to a formula—

$$\delta = aV + bV^2.$$

"The tests made by Warren de la Rue, in which a chloride of silver battery was employed, and which are therefore the only continuous potential tests free from the objection due to the electrostatic machine, agree completely with this formula, over the whole

range up to 11,330 volts. Bourne's tests by means of alternating potentials, reaching up to 110,000 volts, agree fairly well also over

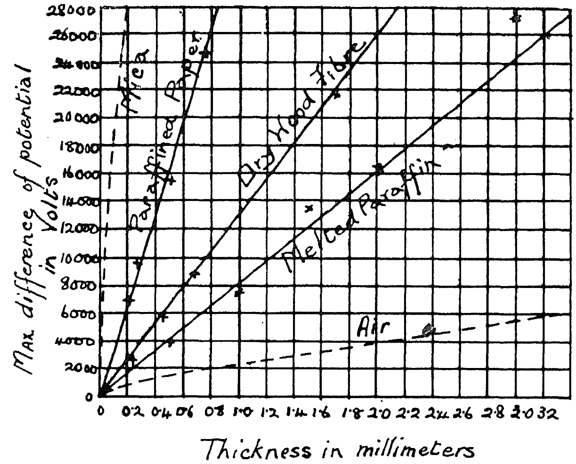


FIG. 38.—Steinmetz' Yonkers Results on Various Insulating Substances.

the whole range. Other tests, again, show agreement with a quadratic formula only within a limited range.

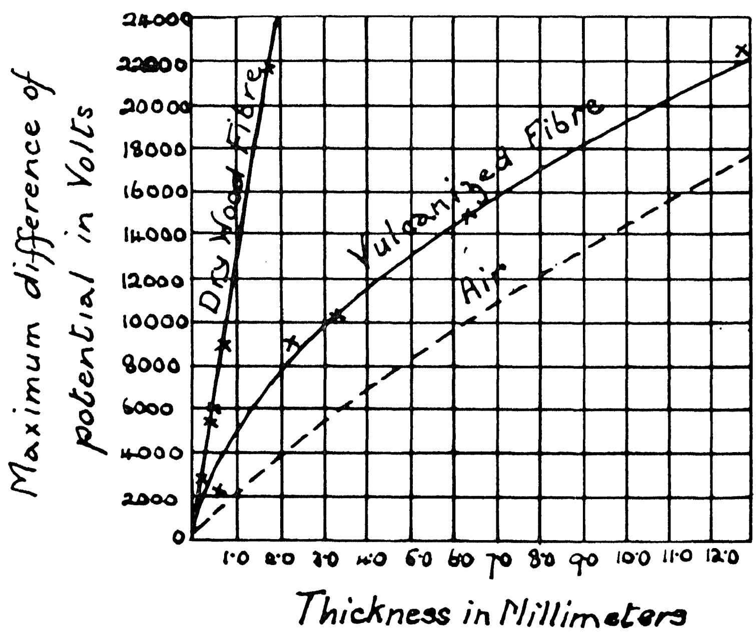


FIG. 39.—Steinmetz' Investigations at Yonkers.

"Most noticeable, however, is the wide disagreement between

the values of different observers, which seems to show that still other factors besides the difference of potential have a decisive influence on the sparking distance."

Steinmetz' tests on mica gave him the curve plotted in fig. 37. The curves for air (fig. 36) and mica (fig. 37) are reproduced by the broken lines in fig. 38, in which curves are also given for melted paraffin, dry wood fibre, and paraffined paper. It will be seen that air and mica constitute limits between which most other insulating substances lie. The curves for air and dry wood fibre are again reproduced in fig. 39, in which a curve for vulcanised fibre is also given.

For vulcabeston and for asbestos paper, Steinmetz obtained the results set forth in Tables XVIII. and XIX.

TABLE XVIII.—STEINMETZ' VALUES FOR THE DISRUPTIVE STRENGTH OF VULCABESTON.

Maximum difference of potential in volts.	Thickness pierced in mm.	Disruptive strength in volts per mm.
4,000	1·0	4,000
6,700	2·0	3,350
10,300	3·0	3,430
12,600	3·55	3,550
3,700	1·56	2,370

TABLE XIX.—STEINMETZ' VALUES FOR THE DISRUPTIVE STRENGTH OF ASBESTOS PAPER.

Maximum difference of potential in volts.	Thickness pierced in mm.	Disruptive strength in volts per mm.
2700	0·60	4500
5000	1·20	4150

The nett results for the disruptive strength obtained in this investigation for a thickness of 0·05 mm. are given in Table XX.

In connection with this investigation, Steinmetz states that "the application of the potential always lasted but a short time—not over 15 seconds. Still, all the materials became more or less heated before breaking down."

Dr Steinmetz shows that the disruptive strength per mm.

TABLE XX.—DISRUPTIVE STRENGTHS FOR VARIOUS MATERIALS FOR A THICKNESS OF 0·05 MILLIMETRE, AS OBTAINED BY STEINMETZ AT YONKERS IN 1892.

Material.	Disruptive Strength in volts per mm.	Remarks.
Air	1,670	
Mica	320,000	
Vulcanised fibre, red . . .	5,200	Slightly damp.
Dry wood fibre	13,000	
Paraffined paper	33,900	
Melted paraffin	8,100	65° Cent.
Boiled linseed oil	8,000	21° Cent.
Turpentine oil	6,400	
Copal varnish	3,000	
Crude lubricating oil (mineral oil)	1,600	Very impure.
Vulcabeston	3,600	
Asbestos paper	4,300	

varies with the thickness in some materials, and remains fairly constant in others. An infinitely small thickness of some materials may thus have a high disruptive strength per mm.

This is shown in Table XXI. for air, mica, and red vulcanised fibre.

TABLE XXI.—STEINMETZ' VALUES FOR THE SPECIFIC DISRUPTIVE STRENGTH FOR VARIOUS SMALL THICKNESSES OF AIR, MICA, AND RED VULCANISED FIBRE.

	Air.	Mica.	Red Vulcanised Fibre.
Disruptive strength in volts per mm. for a thickness of 0 mm.	13,900	417,000	13,000
Do. for 0·05 mm.	1,670	320,000	5,200
Do. for 0·25 mm.	1,190	156,000	1,530

Melted paraffin, paraffined paper, and dry wood fibre are characterised by an independence of the disruptive strength per mm. from the thickness.

CHAPTER V

MICA AND MICA COMPOUNDS

MICA is an anhydrous silicate of aluminium and potassium or sodium. The most transparent qualities are composed of aluminium and potassium silicates, and in the less transparent qualities, magnesia and iron, as well as earthy matter, are also found.

The analysis of a certain specimen of mica is stated to have given the following result:—

TABLE XXIA.—ANALYSIS OF MICA.

Aluminium	35 per cent.
Silicon	46 „
Potassium	8 „
Iron oxide	6 „
Manganese oxide and magnesium oxide	2 „
Fluoric acid	1 „
Water	1 „
Other matters	1 „
	100 „

Mica crystallises in a laminated mass, easily split along the axis.

High percentages of magnesia lend a darker colour to the mica. High percentages of iron colour it grey and black.

It may be subdivided down to a thickness of 0·006 mm. The chief deposits are in India, Canada, and the United States. The distribution of the world's product amongst these three countries is, roughly, 50, 25, and 25 per cent. Fifty per cent. of the world's total product is, however, consumed in the United States. The high cost of mica is not in any sense due to rarity, but to the great difficulty in allocating paying deposits, and in the tremendous waste involved in working the deposits. Thus, in the case of

North Carolina mica, it has been estimated that not more than from 1 to 3 per cent. of the mica taken from the mine finally reaches the market. This is, moreover, less than 0·02 of 1 per cent. of the weight of rock excavated; in other words, for every ton of rock excavated, some 7 ozs. (200 grammes) of mica reach the market.

Large electrical manufacturers obtain their supplies of mica at prices ranging from one shilling to three shillings per kilogram.

India furnishes much of the best mica for electrical purposes, and it is cheap, due to the employment of native labour in the various processes. White mica is the best for electrical purposes. Green shades of mica are amongst the softest qualities obtainable. White amber, most of which comes from Canada, is the most flexible.

The best clear ruby mica will at certain places in a sheet sometimes have a disruptive strength of 12,000 R.M.S. volts per tenth of a millimetre, but the average values will be far lower. Curves of the disruptive strength of mica have already been given in figs. 1 and 37. Others will be given in the course of this chapter.

The high insulating qualities of mica and its ability to withstand high temperatures have made it a material of great importance to the manufacturer of electrical apparatus. On the other hand, its lack of flexibility and of uniformity, and its tendency to permit surface leakage,[1] have constituted very considerable disadvantages. To overcome these disadvantages several kinds of reconstructed mica, termed respectively micanite, megohmit, megotalc, etc., have been placed on the market by different manufacturers.

Micanite.—In the manufacture of micanite, the mica is first split up into laminæ, and these thin sheets are reassembled and stuck together by an insulating cement, and with the application of high pressures and temperatures. Micanite, when heated, may be bent into suitable forms. Natural mica cannot be bent except

[1] "A very important test which should not be overlooked is the galvanometer test for leakage, as some materials may be good against piercing and yet be bad from a leakage point of view. Take mica-paper for instance. This, if the mica is well laid—that is, with all joints well lapped—will show well under a disruptive test, but for leakage would depend entirely on the mucilage or varnish with which the mica flakes are built up."—"On Insulation," the *Elec. Eng.* for September 16, 1904, p. 413.

in the thinnest component laminæ, for in a piece of any thickness the different laminæ adhere immediately to one another, whereas the freedom of movement possible with micanite is essential to bending without fracture. The function of the cement with which the laminæ are stuck together is such that, when heated, it allows the different layers of the laminated mica to slip slightly over each other, and in this way to allow the mica to conform, when heated, to any surface to which it may be applied, and if allowed to cool in a mould, it will retain its form, and will be so dense as to emit a metallic ring when struck. It is claimed by the manufacturers of micanite that the cement introduced is of a composition ensuring the absolute exclusion of all moisture, and that the finished product is impervious to moisture. It is, however, known that in much reconstructed mica (not necessarily especially in the product manufactured under the trade name of micanite) shellac is used in sticking the sheets together, and this softens too readily at moderate temperatures, and is, furthermore, objectionably hygroscopic.

The results in Table XXII. were obtained by Herrick and Burke for the disruptive strengths of micanite products.

TABLE XXII.—HERRICK AND BURKE'S RESULTS FOR THE DISRUPTIVE STRENGTHS OF VARIOUS MICANITE PRODUCTS.

Material	Disruptive strength in volts per one-tenth millimetre when cold.
Micanite plate	4000
Flexible micanite plate	2000
Micanite cloth	1700
Micanite paper	1800

Micanite plates are made in thicknesses of 0·25 mm. to 3·0 mm., and in two qualities, No. 1 and No. 2.

No. 1 softens when heated, and is easily moulded to form.

No. 2 is intended primarily for commutator segments, and the cement will not ooze out when heated.

So-called "flexible" micanite plates are made in two styles, A and B.

Style A, which may be obtained in any thickness not less than

0·25 mm., will retain its flexibility for years, and whenever warmed its flexibility is still further increased. It is similar to flexible micanite cloth, but without the addition of the muslin and paper employed in the latter. It is non-absorptive, and is used for insulating armature slots and coils, armature and field magnet cores, and whenever a sheet mica insulation is preferable to tape or fabric.

Style B is a cheaper quality, made from selected pure India sheet mica, split exceedingly thin.

Micanite cloth and paper are made, the former with fine muslin on one side and paper on the other, and the latter with paper on both sides. Each is made in three thicknesses, with one, two, and three layers of mica respectively.

TABLE XXIII.—VARIETIES OF MICANITE CLOTH AND MICANITE PAPER.

No. of Layers of Mica.	Thickness in millimetres.	
	Micanite Cloth.	Micanite Paper.
1	0·20	0·13
2	0·28	0·20
3	0·36	0 28

There are also qualities designated as extra-flexible micanite cloth and paper.

Troughs, rings, tubes, field magnet and transformer spools, commutator segments, and moulded end and band rings, are also manufactured from micanite. A number of instances are shown in figs. 40 to 42.

Megohmit.—Megohmit has been developed for the same purposes for which micanite is employed. The manufacturers of megohmit make the statement that, owing to the large percentage of adhesive matter exuding from other composite micas when hot, they have been found unsuitable for use in commutators. Other methods of insulation by paper or by mica paper are stated to have been found useless. To supply these wants they have produced megohmit, a material of soft quality, in which the adhesive matter has been extracted in various ways, showing by chemical analysis that

the adhesive matter in no part of the whole of the finished plate exceeds 1·25 per cent.

Although small plates of megohmit are dearer than similar sizes in mica, the saving arises when large sizes are required, where pure mica would be too expensive. Plain and flanged commutator rings and collars are made from megohmit. The same manufacturers make both hard and flexible megohmit plates, and also so-called mica paper and mica linen.

The plates consist of thin mica sheets, stuck together with shellac in the case of the hard plates, and with a mixture of

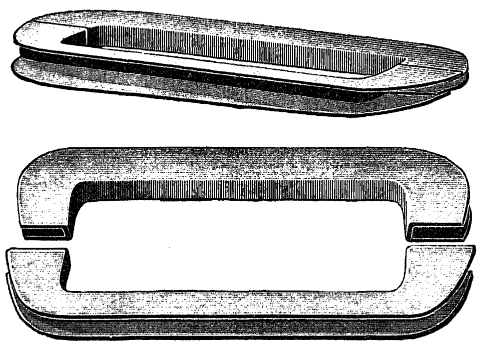


Fig. 40.

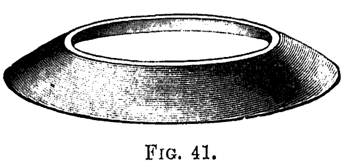


Fig. 41.

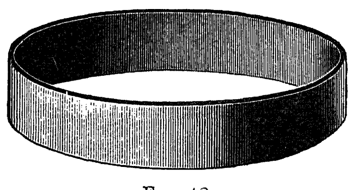


Fig. 42.

Moulded Forms of Micanite.

various vegetable adhesive materials in the case of the flexible plates.

The mica paper consists of flexible plates having a covering of Japanese paper. The mica linen consists of flexible plates with a covering of linen. The hard plates have the advantage, as against the flexible material, of being entirely waterproof and of withstanding greater mechanical pressure, as well as of possessing greater insulation resistance. The hard plates

become soft at about 80° Cent., but on cooling, regain their original mechanical strength without the insulation having been affected. Channels, troughs, and tubes may be manufactured from megohmit plates.

The specific gravities of these various megohmit products are as follows:—

TABLE XXIV.—SPECIFIC GRAVITIES OF VARIOUS MEGOHMIT PRODUCTS.

Material.	Specific gravity.
Hard megohmit (B quality) . .	2·5
Flexible ,, ,, . .	2·0
Mica paper	1·5 to 1·9
Mica linen	1·2 to 1·8

The manufacturers of megohmit have a system of mica slot insulation, according to which the slot tubes have long lapped and tapered joints, so that the walls of the tubes are maintained of equal thickness, whilst the winding may be laid in with the same ease as in open channels.

In figs. 43 and 44 such a tube, first opened and then closed, is shown. Figs. 45 and 46 show different forms for the lap joints. Still further security is afforded by the arrangement illustrated in fig. 47, in which one tube is placed inside another, the lapped joints being at opposite sides.

Some groups of megohmit commutator rings, and some channels, troughs, and tubes, are shown in figs. 48 and 49.

Some interesting curves of the properties of megohmit, supplied to the authors by the kindness of the manufacturers, are reproduced in fig. 50.

Of these curves the puncturing curves show the voltage at which the different thicknesses of the materials are broken down immediately upon the application of the voltage, when in the cold condition. The heating curves show the voltage which a material of given thickness will sustain continuously without experiencing a temperature rise of more than 3° Cent. above the surrounding air.

For the tubes for continuous-current and alternating-current

machines, a second set of temperature curves has been taken, which, referred to the basis of the 3° Cent. rise occasioned by the electric stress, shows the maximum possible temperature rise which an electrical stress corresponding to a given voltage can occasion in tubes of given thicknesses.

The manufacturers state that these curves are deduced from the results of many thousands of tests, amongst which were many

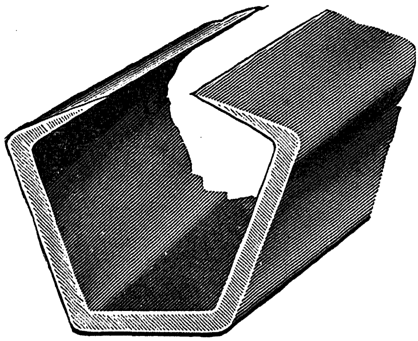


FIG. 43.

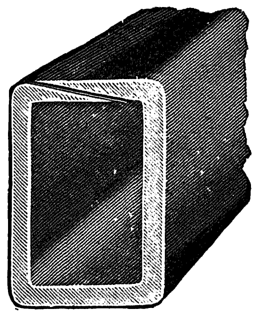


FIG. 44.

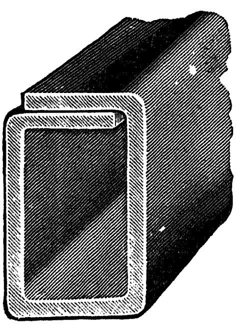


FIG. 45.

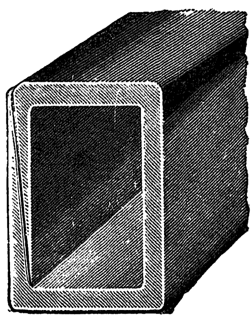


FIG. 46.

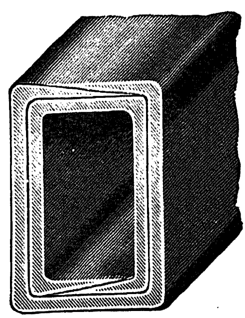


FIG. 47.

Megohmit Slot Insulations.

duration tests. These tests were all carried out at their own laboratory. The manufacturers further state that the results given by the curves are exceeded by about 20 per cent. by their improved method of manufacture to-day.

Megotalc.—Still another reconstructed mica product is termed megotalc. Its manufacturers state that it is made of mica sheets

of the best quality and with the least possible amount of shellac. Their products are classified as—

Megotalc plates,	Megotalc paper,
Megotalc cloths,	Megotalc cloth paper,

and these are all supplied for any of the customary range of

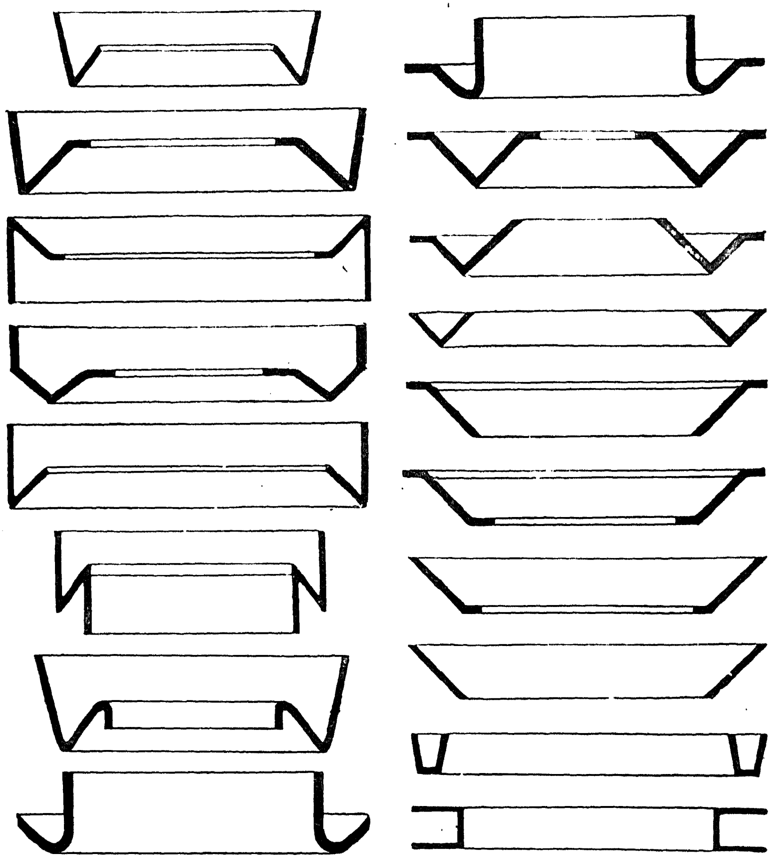


FIG. 48.—Moulded Megohmit.

required thicknesses. Two groups of megotalc products are shown in figs. 51 and 52.

Dr Walter's Investigations on Mica.—Dr Walter made tests on five varieties of normal mica, and found relatively ··le difference in their disruptive strength so long as he avoided ng the weak portions, which were readily discovered in ad- ɘ of the final tests by his method of testing, by passing the

plate in all directions between the electrodes before preparing the surface with wax for the quantitative test. In such a preliminary test some plates of mica easily withstood spark lengths of 100 times their thickness, whereas faulty spots broke down with spark lengths of but 50 times the thickness of the plates. In the final tests of sound plates, with the surface prepared with picein drops, according to the method already described (pp. 43 to 48), the results set forth in Table XXV were obtained.

TABLE XXV.—WALTER'S TESTS OF NATURAL MICA

Source	Colour	Thickness tested in centimetres	Spark length in centimetres, per centimetre thickness	Inferred R.M.S. disruptive voltage per mm. thickness
German East Africa	Light brown when in thick layers	0·0045	56	28,000
	Remarkably clear and completely free from impurities	0·0075	57	28,500
Calcutta	Light ruby colour when in thick layers. Occasional brownish and yellow impurities	0·0048	35	17,500
Madras	Rather numerous spots of reddish and greenish colour. Thicker layers showed a characteristic green tint. Very soft. Excellent for commutator segments	0·0065	49	24,500
Korea	Clear yellowish shade, with black coloured impurities	0·0049	42	21,000
Ceylon	Even in thin pieces this variety showed a greenish discoloration. Thick layers showed a very dark reddish yellow colour	0·0060	40	20,000

During these investigations Dr Walter made some observations which throw light upon the behaviour of micanite.

Taking a natural mica plate with an air bubble below the surface, he tested the plate by means of the picein-drop method, from directly above the air bubble. He found that with a spark

length corresponding to the disruptive strength of the plate, it only broke down from the perforation in the piceïn drop to the air bubble, the remainder of the plate remaining unperforated until a considerably greater voltage had been applied. Even then it broke down, not in the continuation of the first puncture, but from one side of the air bubble.

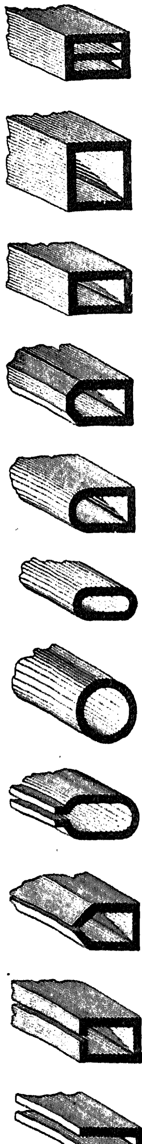


FIG. 49.—Moulded Megohmit.

These occurrences he explained by regarding the air bubble as a protection for the remaining half of the plate, in that it allowed the electricity to again spread out over the whole surface of the bubble, and thus relieved it from the concentrating action of the original perforation in the piceïn drop. This theory he confirmed by testing two plates of glass on top of one another. With the spark length which would have broken down a single plate of glass of the double thickness the upper part was perforated, but a substantially doubled voltage was necessary to bring about the perforation of the second plate. This satisfied Dr Walter that his method is only suitable for tests of homogeneous samples. Thus he found that micanite plates withstood spark lengths of from 70 to 200 times the thickness of the plates, whereas natural mica plates only withstood spark lengths of from 35 to 57 times their thickness.

It would thus appear that a great advantage may be gained in certain cases by the use of reconstructed mica (micanite) instead of natural mica. On the other hand, in the case of such non-homogeneous samples, Dr Walter discovered a corrosive action at the surfaces of the intermediate layers. The voltage would break down an outer layer, and, in the neighbourhood of the puncture, the next lower layer would be subjected to a gradual deterioration accompanied by local heating, and the puncture would ultimately extend to another layer, although not necessarily in a continuation of the axis of the first puncture. The chief danger is that this

action goes on unobserved, whereas with a homogeneous material a puncture of the surface is proof of the existence of a complete puncture, and an unpunctured surface is a guarantee that the insulating properties of a homogeneous substance are unimpaired.

A good equivalent for these reconstructed mica insulations may

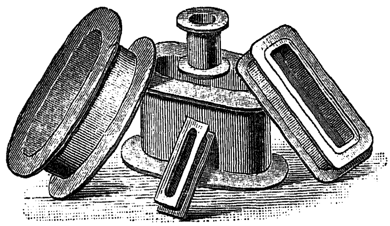


FIG. 51.

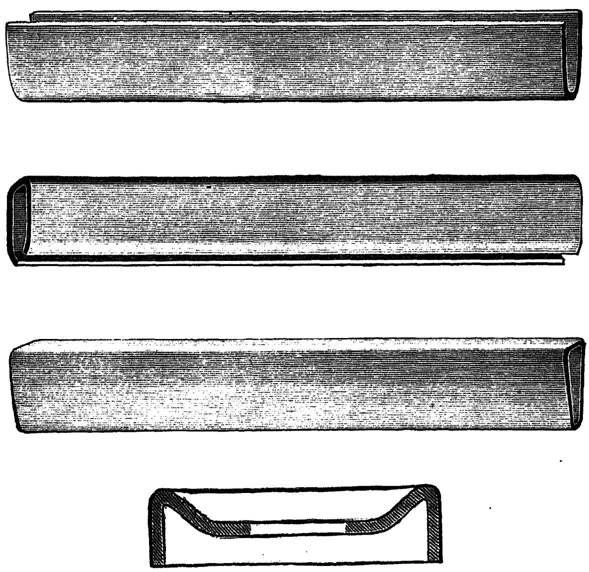


FIG. 52.

Forms of Megotalc.

be made from presspahn and mica. The method is described in Chap. XIV., and moulded tubes and troughs of this material may be made to withstand some 12,000 volts per millimetre, and will much less readily lose their shape.

A great fault of mica is susceptibility to rapid deterioration under the influence of oil. This leads to difficulty, more especially

with respect to commutator insulations, and will be considered more at length in that connection.

Mr Farrington [1] takes the stand that the fault is not due directly to the influence of the oil. His argument is as follows:—

"Green discoloration is evidence of inconstancy where constancy is indispensable. As it is very seldom seen except as a relic of a broken-down machine, it may therefore be said to be coincident with burned-out and short-circuited machines. But this discoloration becomes more potent in its suggestiveness as we consider what takes place to produce such a radical physical change—a change visible to the naked eye—a change positive and far-reaching enough to send the green colouring matter through mica $\frac{1}{16}$ in. (1·6 mm.) thick, and to impregnate thick wrapping paper and fibre stock. In the study of this action we need accept nothing but the facts and authority which are beyond dispute by being common knowledge. When we see a piece of mica that was once a beautiful amber colour turned green, when we find that it would stand a puncture strain of 10,000 volts while of amber colour, and can be punctured with 1000 volts since its colour has been altered, and we find that it has actually failed to prevent the passage of a current of not over 10 volts, we have a right to conclude that there is a relation between such green discoloration and concurrent drop in insulation resistance, and we have a right to carry that conclusion a step further, and decide that the short-circuit was caused by the chemical transformation of which the colour change is evidence.

"At least we are justified in a further exploration and examination, in the light of the simplest variety of information on a simple chemical action. By doing so we find it is easy for a varnish to have a chemical effect upon copper. Such action is the rule rather than the exception; and now, by reference to well-known authority, we find that this green action is the characteristic one of acids upon copper. The presence of acids near copper is always evidenced by green discoloration. Vegetable acids substitute atoms of copper for atoms of hydrogen, in common with other acids. We are justified in concluding that such substitution of copper for hydrogen takes place in a gaseous or semi-gaseous

[1] Franklin Institute, March 12, 1903.

state. We shall now be able to apply the knowledge that vaporised copper has a high conductivity, and we shall then come to an unassailable conclusion that during the time when that mica was being impregnated with that vapour or varnish-copper the insulation of the mica was so reduced that an easy passage was afforded to the 8 or 10 volt current which effected the short-circuit.

"When we find that the green discoloration may take place in an idle machine and not short-circuit it, and that short-circuits always appear when the green discoloration takes place in a machine which has been constantly in operation, we obtain further proof of a positive nature that acids should not be permitted to enter into coil construction under any circumstances,—not even when they are loaded with black colouring matter to cover up their corrosive action.

"In this connection we exploded one of the superstitions of the electrical fraternity—the notion that lubricating oil caused short-circuits. Lubricating oil never will, never did, it never can cause a short-circuit. If we could design a generator which would run in oil, immersed in oil just as transformers are built, we should undoubtedly produce a successful machine. Why, then, should lubricating oil cause a short-circuit? The first electrician who had a short-circuited machine was naturally disappointed and wanted an excuse, and when he found that lubricating oil had penetrated into the coils, he accused it of causing the trouble. What actually occurred was this: The lubricating oil came in and stirred up the dormant or satisfied acids of the varnish which he had used. Varnish makers who have essayed to manufacture insulating compounds have on several occasions claimed that their varnishes were oil-proof. Varnish salesmen sometimes attempt to prove that an insulating varnish is oil-proof because they can coat a newspaper with it, and the newspaper will hold oil in the open air, and away from the heat of operating apparatus. As a matter of fact, varnish which is so proved to be oil-proof will unite readily with lubricating oil under a temperature of 150° F. (66° Cent.). The trouble is that it will not unite homogeneously. The oil unites with one part of the varnish and separates that part from the balance of the varnish, so that

there are two or three separate and distinct bodies
originally but one. In one or both of these, the

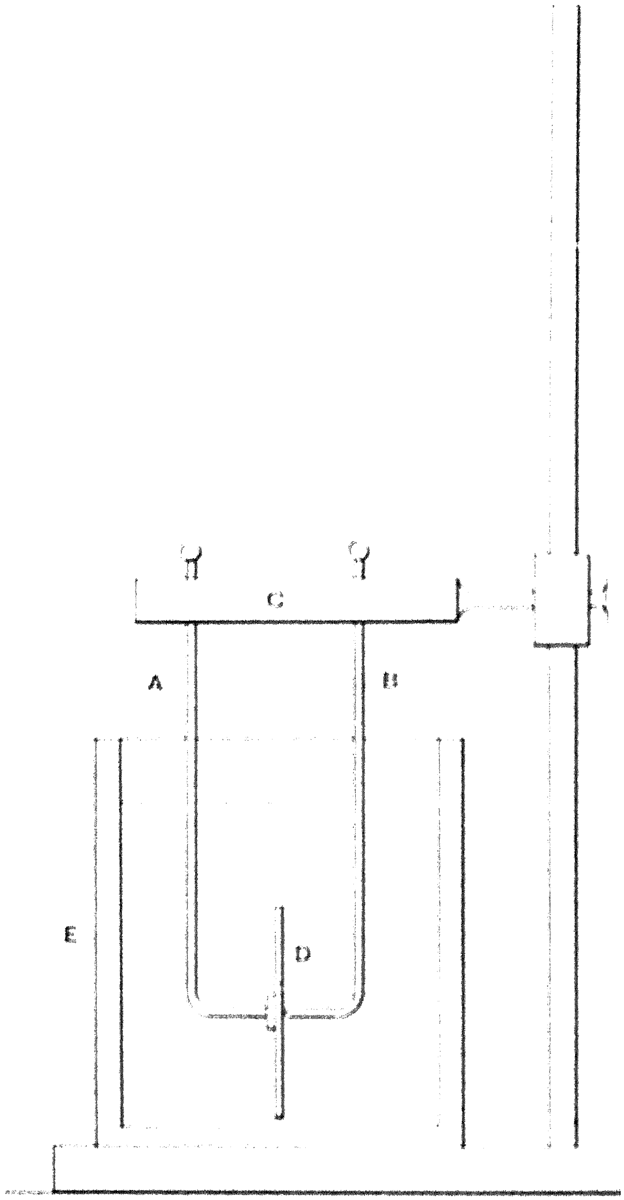


FIG. 53.—Andrews' Apparatus for Testing the Disruptive Strengt
Materials immersed in Oil

tisfied, and they immediately attack the copper,

described, cause the short circuits which were attributed to lubricating oil.

"The oil was innocent. It is absolutely indispensable, and the acids of acid insulations are not indispensable.

"Inasmuch as it is feasible, by working in the paraffin series, to make non-acid insulating compounds which have complete chemical affinity for lubricating oil, it is perfectly easy to obtain

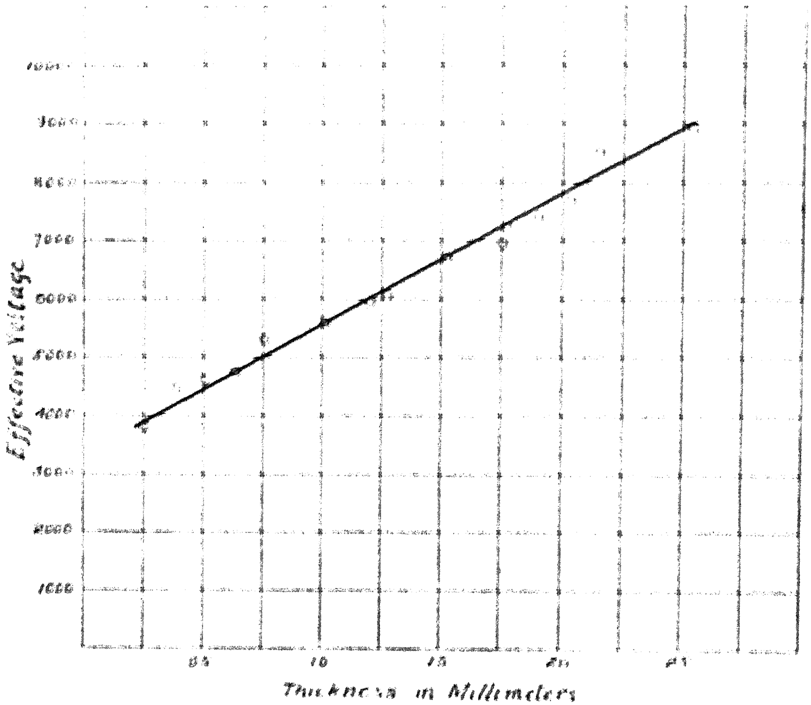


FIG. 54.—Andrews' Curve for Puncturing Voltage of Clear White India Mica when immersed in "Transil" Oil.

insulation for a machine which will be friends with and welcome all the good insulation which may soak into it from its bearings in the form of oil."[1]

[1] While Mr Farrington's views with regard to the effect of oil are of interest, we certainly cannot agree with him when it comes to the effect of oil on commutators, where the harmful effect of the oil in saturating the mica insulation, and leading to the accumulation thereon of copper and carbon dust, is the real cause of break-down in 90 per cent. of all defective commutators. We revert to this matter in the section relating to the insulation of commutators.

The effect of oil on mica has been investigated by Härden and by Andrews. The following extract is made from an article by John Härden in the *Electrical World and Engineer* for April 18, 1903, entitled "Effects of High Potential on Mica Insulation":—

"Mica placed between a point and disc of high potential difference is subjected to a radial discharge over its surface from the point, which should be of the plus sign. This energy is transformed into heat, so that the mica becomes quite hot.

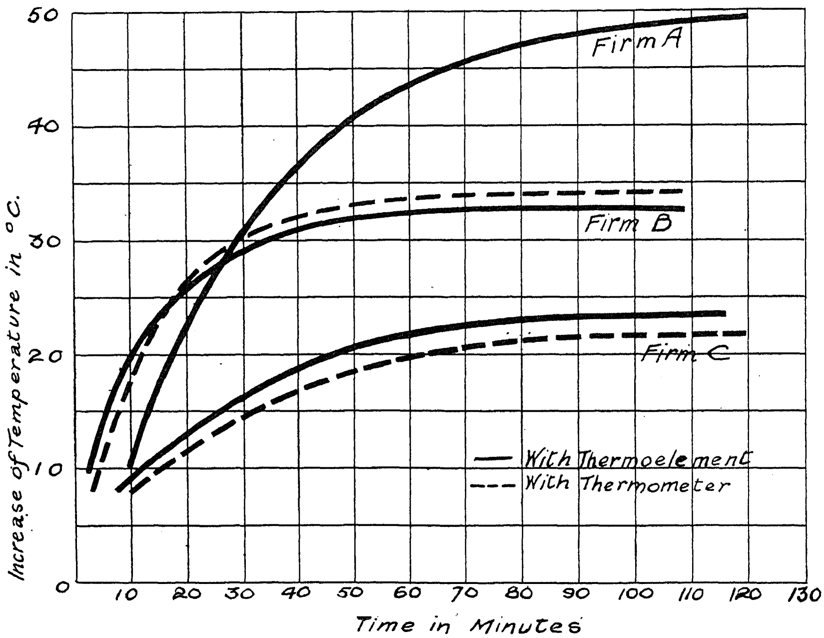


FIG. 55.—Holitscher's Tests on the Heating of Micanite Tubes when subjected to Dielectric Stress.

"Since the discharge has the same sign, the particles repel each other, and the discharge is spread over the whole surface. This distribution of the electric charge on the surface of the dielectric is combined with a fall of potential over a unit of surface, or, in other words, the electric pressure per unit of surface is less. Oil placed on the point, or around it, will tend to concentrate the radial discharge, increasing thereby the pressure per unit of surface. Mica which stood 9000 volts before, will not now stand more than 6000 volts. Paraffin and sealing-wax produce the same effects. Varnished paper or cloth do not show these

effects, because the heating effect of the radial discharge melts the varnish, and this forms a ring like the oil around the point of contact. Investigation with sealing-wax on varnished paper gave quite the same results as on mica, these being, that varnished paper of the same insulating quality as mica breaks down with a lower potential difference than mica.

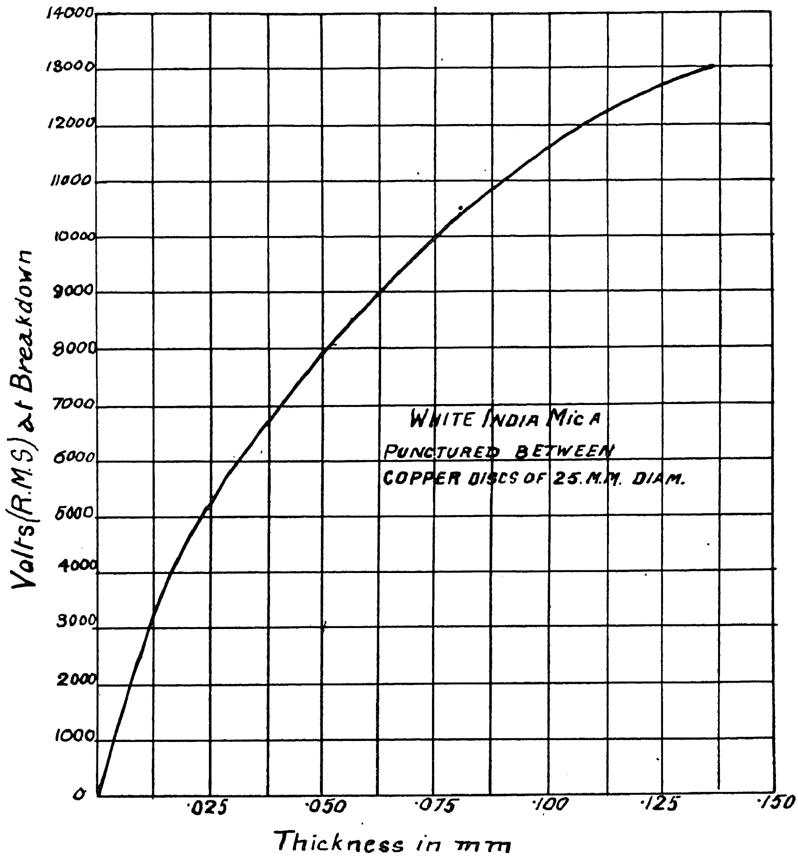


FIG. 56.—Dielectric Mfg. Co.'s Curve of the Disruptive Strength of Solid White India Mica.

"The results of the whole investigation go to show that a solid insulation combined with mica, in condensers or similar apparatus, would be most effective without the use of oil. A good insulating jelly, free from air bubbles, would be an advancement."[1]

[1] The reader should reflect upon these statements after consulting the footnote on p. 27, and should also consider the relation of these observations

The matter had also been discussed nearly a year earlier, *i.e.* at the Great Barrington meeting of the Am. Inst. of Elec. Engrs. on June 20, 1902. The following account of Andrews' tests is extracted from the *Trans. Am. Inst. Elec. Engrs.*, vol. xix. p. 1063:—

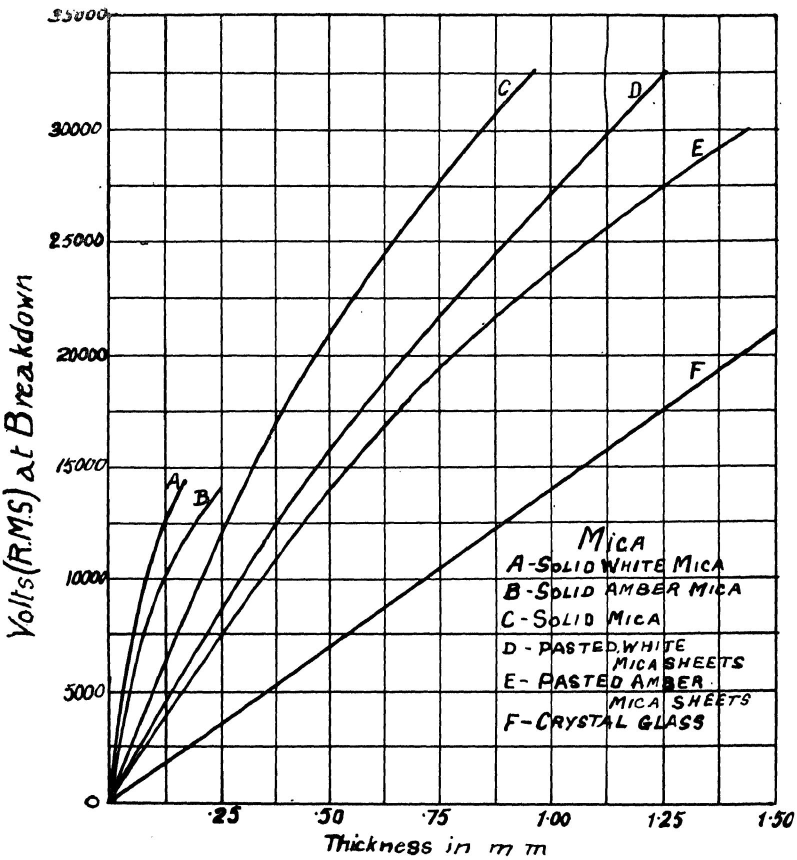


FIG. 57.—Dielectric Mfg. Co.'s Curves for Various Qualities of Solid Mica, and for Pasted Mica, and for Crystal Glass.

"The tests were made with alternating current delivered at 118 volts, 60 cycles. The voltage was raised by a small step-up transformer, with the necessary regulating devices, and measured by a static voltmeter reading up to 10,000 volts. A good quality of clear white Indian mica was used, a dry sheet of which,

to Dr Walter's experience with his "piceïn-drop" method, described on pp. 43 to 48 and pp. 91 and 92.

0·002″ (0·051 mm.) thick, would stand a pressure of 8000 R.M.S. volts for an indefinite time in air.

"The sketch in fig. 53 shows the general arrangement of the testing apparatus. A and B are two brass rods, supported by a piece of hard rubber C, and bent towards each other at right angles at their lower ends. One of these rods terminates in a brass disc about $\frac{3}{8}$″ diameter, and the other rod is finished with a rounded point touching in the centre of this disc. This rounded point rests against the disc with sufficient pressure to support the piece of mica D that is to be tested. These parts are attached to a stand, so that the holder with mica may be lowered into a vessel E containing oil. Preliminary experiments were made with various kinds of oil, but no difference in results could be observed, so it was decided to use a good quality of transil oil for the present tests.

"The figures in Table XXVI. (also plotted in fig. 54) show the average puncturing voltage derived from a number of tests made on each thickness of mica used.

TABLE XXVI.—ANDREWS' RESULTS FOR THE DISRUPTIVE STRENGTH OF MICA WHEN IMMERSED IN OIL.

Thickness of Mica.	Average puncturing Voltage.
·001 ins.	3800
·0015 "	4500
·002 "	4600
·0025 "	4750
·003 "	5300
·004 "	5570
·00475 "	5950
·005 "	6050
·006 "	6700
·0065 "	6930
·007 "	7220
·0075 "	7400
·008 "	7700
·0085 "	8550
·01 "	8900

"It is not necessary to place the mica under the oil in order to reduce its puncturing resistance. If a piece of mica, say ·002″ thick, is supported in the holder shown in the sketch, the holder and the mica being quite free from oil, the pressure may be

raised to about 8000 volts, and if the mica is of good quality it will stand the strain indefinitely, but if a drop of oil is applied to the blunt metal point the mica will be instantly punctured.

"It is curious that oil does not seem to produce any weakening

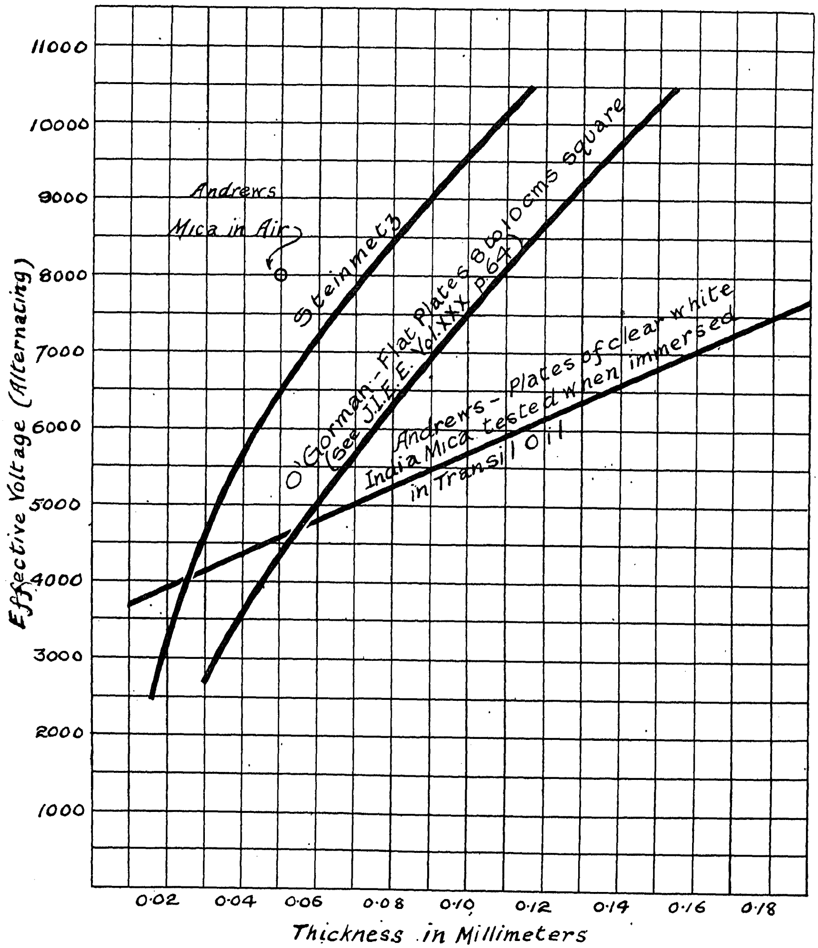


FIG. 58.—Curves published by Different Authorities for the Disruptive Strength of Mica.

effect on artificial insulators, such as paper coated with boiled linseed oil, copal varnish, etc. The results of many tests show that the resistance to puncture of these materials remains about the same, whether tested in air or under oil."

It has been suggested to the authors that the mica breaks down

at the lower voltage because the oil prevents surface leakage, and the potential stress is reduced to the pointed electrode. If plates had been used instead of points it would probably have been found that the mica punctured at a lower voltage than in air, but at a higher voltage than between pointed electrodes in oil.

Holitscher (*E.T.Z.*, 1902, p. 171) has obtained the following results from tests of materials of the micanite type, supplied by three different firms. The thickness was 1·0 mm. in each case.

TABLE XXVII.—HOLITSCHER'S TESTS ON MICANITE WHEN FLAT AND BENT, AND WHEN COLD AND WARM.

Firm.	Disruptive Strength in R.M.S. Volts.			Amount of the Adhesive Material exuding when subjected to pressure while warm.
	Cold.	Warm.		
		Flat.	Bent.	
A	25,000	25,000	23,000	Much
B	25,000	22,500	20,000	Much
C	24,000	23,000	23,000	Little

Holitscher also investigated micanite tubes, supplied by three firms, with regard to the heat developed in them by prolonged test at a given high potential and at a given periodicity. The samples were all of practically the same dimensions. The results are plotted in the curves of fig. 55, and show a considerable difference in this respect in the product of different firms. The product of a fourth firm showed a rise of temperature of 100° Cent. after only 15 minutes' test.

Some curves for solid mica of various qualities, and for pasted mica, taken from a publication of the Dielectric Manufacturing Co., of St Louis, Mo., U.S.A., are given in figs. 56 and 57. Some other curves on mica are brought together in fig. 58.

CHAPTER VI

INSULATING MATERIALS FOR BUSHINGS, TERMINAL BLOCKS, FLANGES, ETC.

FOR bushings, terminal blocks, brush-holder appliances, collector ring constructions, spool flanges, etc., there is now widely used a

FIG. 59.—Ambroin.

class of moulded compound insulators, where formerly hard rubber, vulcanite, thick fibre, and leatheroid, and even wood, were employed. Glass and porcelain are also used.

The precise compositions of most of these moulded materials are generally regarded as trade secrets, although in some cases a general statement of the leading ingredients is available.

Ambroin.—Ambroin is stated to be composed of fossil copal and silicates, the silicates being saturated and mixed with the copal by a special process, by which a strong, firm, uniform, durable, homogeneous and non-hygroscopic material is stated to be produced. In figs. 59, 60, and 61 are shown respectively groups

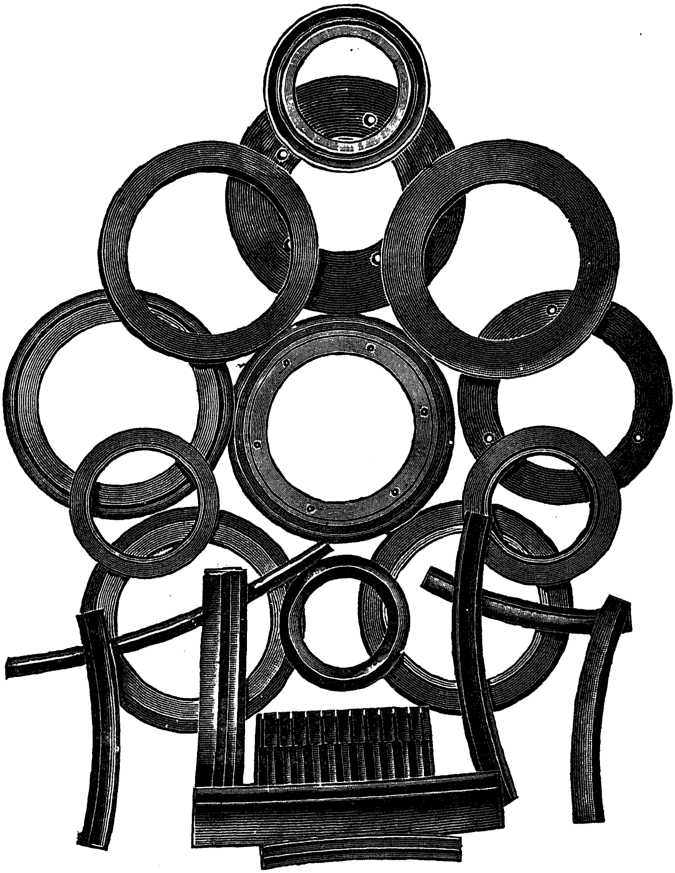


Fig. 60.—Ambroin.

of bushes and washers, commutator rings, and bobbins and spools, all moulded from ambroin. The material has been extensively employed for these purposes, but care should be taken in ordering the correct composition, as most grades rot when subjected to contact with oil. The writers' own opinion is that the material is certainly not equal to the requirements of commutator construction, *i.e.* for end insulating and finishing

rings of commutators. It is certainly very useful in many cases for insulating bushes and flanges. It can be moulded about metal parts, and should thus often be useful in brush-holder constructions and in other details of the design of dynamo-electric machinery.

In Table XXVIII. is a list of the qualities in which ambroin is made.

TABLE XXVIII.—VARIOUS GRADES OF AMBROIN.

F.W.	Absolutely fire-proof, only suitable for arc shields.
S.F.W.	Practically fire-proof, only suitable for arc shields.
F.	Ordinary fire-proof.
F.S.	Ordinary fire-proof, but faced on one side with a layer of absolutely fire-proof material.
H.F.	Suitable for use where temperatures up to 212° Fahr. (100° C.) prevail.
A.F.	Suitable for use where temperatures up to 180° Fahr. (82° C.) prevail.
B.A.S.	For high-tension purposes and accumulator boxes (acid-proof).
A.M.	Non-magnetic, for temperatures up to 180° Fahr. (82° C.).
A.M.F.	Non-magnetic and fire-proof.
Pl.F.	Ambroin fibre, suitable for thin washers, etc., but not for high-tension purposes.
A.B.S.	Alkali and acid proof.

Ambroin has a specific gravity of 1·4 to 1·8 according to the quality.

Ambroin is considerably cheaper than ebonite, and, moreover, is stated to offer a greater resistance to high temperatures, and not to be affected by exposure to the weather. It is claimed that it does not undergo any variation in volume after having been subjected to pressure in the moulding process, and this, which is not the case with ebonite, for example, ensures accuracy in the most complicated pieces, while parts of insulators made up of a number of pieces that may be subjected to wear, can be replaced without difficulty. Unless a high polish is required, no subsequent machining is necessary, as the insulators are said to leave the mould exact to dimensions and ready for use.

It is stated that ambroin can be turned and drilled, cemented with acid-proof ambroin cement, and polished like wood.

Ambroin in the open air is claimed not to absorb moisture. This is not the case with stabilit, vulcabest, vulcanised fibre, etc. This not only increases its value as an insulator, but decreases the danger of the destruction of the insulation owing to the water taken up freezing in winter.

As the materials used in the production of ambroin are claimed

to be such as have been exposed to atmospheric changes for centuries, its destruction through exposure should be impossible. Ingredients which oxidise or are otherwise affected by the atmosphere, as for example sulphur in ebonite, are said not to be contained in ambroin.

The manufacturers give the following tests as showing the relative amount of water absorbed by ambroin and various materials.

Pieces of equal size and with smooth surfaces were taken, and

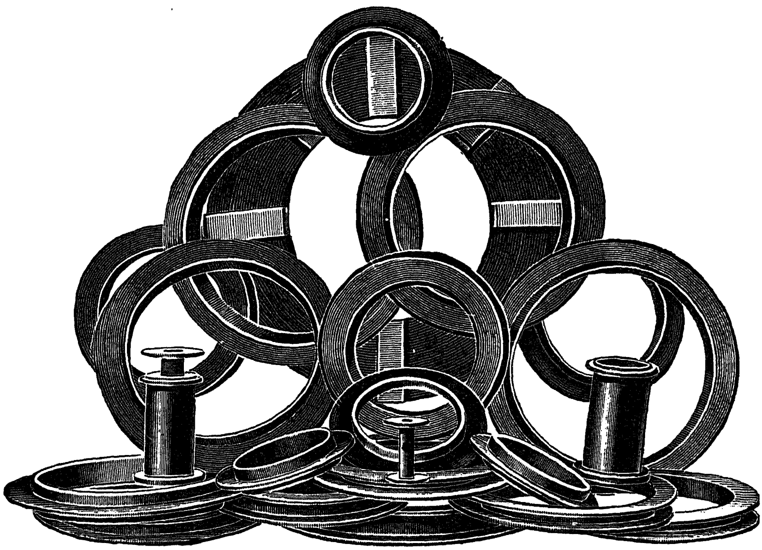


FIG. 61.—Ambroin.

after being immersed in water at 16° Fahr. for 1½ hours, the increase in weight was as set forth in Table XXIX.

TABLE XXIX.—COMPARATIVE TESTS OF AMBROIN WITH OTHER MATERIALS.

1. Ambroin (quality A.F.)	0·32 per cent.
2. Aetna material (the surface became rough)	3·17 „
3. Stabilit	1·41 „
4. Vulcabest	4·80 „
5. Vulcanised fibre	24·50 „

It is stated that these figures serve at the same time as a reliable comparison of the value of each of the materials when used as insulators in the open air or in damp rooms.

Insulation Strength—(Tests quoted by Manufacturers).—The

resistance of dishes, about 3 mm. thick, firmly pressed between electrodes of 25 sq. mm. surface, was measured with 200 volts:—

1. Without preparation, 200,000 megohms were obtained.
2. The dishes were half-filled with sulphuric acid, 26° Bē, covered up and subjected to a temperature of 120° Fahr. (49° C.) for ten days in a thermostat. After a superficial drying with blotting paper the resistance the following day was 150,000 megohms, and two days later 200,000 megohms.

Tests of Dielectric Strength.

(*a*) Tests with moistened slabs:—

I. The slabs were placed in water, which was gradually heated up to boiling point, and after the water had been allowed to cool down to about 85° Fahr. (30° C.) the slabs were taken out.

(1) Aetna material, 1 mm. thick, was pierced with 3500 volts.

(2) Ambroin (quality A.F.), 0·33 mm. thick, was pierced with 3500 volts, while a piece 0·84 mm. thick was not pierced with 5000 volts.

II. A slab (quality A.F.), 5 mm. thick, after lying in a room, the air being at 95 per cent. saturation, for several days, was not pierced with 36,000 volts.[1]

Heat-resisting Qualities.—It is claimed that ambroin (quality A.F.) only commences to burn, and then only after the source of heat has been applied for some time, at a temperature of 750° Fahr. (400° C.). Commutator rings made of this quality are stated by the manufacturers to have been proved satisfactory after having been subjected to heat for many hours in contact with oil.

The qualities made for special purposes, such as the arc shields in controllers, switches for motors, etc., withstood the hottest zone of a Bunsen flame (about 3000° Fahr.), so that the use of such qualities is recommended by the manufacturers of ambroin where, in consequence of possible short-circuits, arcing takes place, and momentary high temperature is reached.

The following examples are given by the manufacturers for

[1] These tests were made by the Reichsanstalt, Berlin.

comparison:—Ebonite and celluloid soften in water, even at a temperature of 160° Fahr. Celluloid commences to burn rapidly at 230° Fahr., and ebonite burns at 350° Fahr.

Ambroin (quality B.A.S.) at a temperature not exceeding 180° Fahr. is not affected by sulphuric acid up to 45° Bē, nor by concentrated hydrochloric acid. Cold nitric acid of 24° Bē does not affect it to any appreciable extent; only a slight nitration of the surface takes places.

Quality A.B.S. withstands caustic soda solution up to 30 per cent. concentration, as well as acetic acid up to 50 per cent.

Ambroin under compression or tensile stresses is superior to all insulating materials made of rubber or recent gums.

Tests quoted by the manufacturers gave the following results:—

A. *Tensile Strength.*

While ebonite stretched considerably between 120° and 160° Fahr., ambroin proved to have a greater tensile strength at this temperature than when cold. The following results were therefore obtained at normal temperature with rods of equal diameters, and give the breaking stresses for each material:—

1. For ebonite, . . .	1120 lbs. per sq. inch.		
2. For Aetna material, . .	1400	,,	,,
3. For ambroin (quality A.F.), .	2140	,,	,,

B. *Compressive Strength.*

Cubes, which presented a surface of one square inch to the pressure, gave the following results:—

1. At normal temperature, ambroin was destroyed at 2680 lbs.[1]
2. At normal temperature, ebonite was destroyed at 2200 lbs.[1]
3. Aetna material (at normal temperature) was destroyed at 728 lbs.

At 140° Fahr., ambroin was destroyed at 1960 lbs.,[1] while ebonite gave way under a very small load.[1]

[1] These tests were made by the Royal Mechanical Testing Laboratory, Berlin.

Directions for machining Ambroin.

Sawing.—With a band saw having a very hard saw and running at about 300 revolutions per minute. Very slow feed.

Drilling.—In a dry state with a flat drill, which allows the shavings to pass away freely. From 400 to 500 revolutions per minute, according to the diameter of the drill.

Turning.—With suitably ground tools made from hard cast steel files. From 400 to 500 revolutions per minute, according to the diameter of the work.

Grinding.—By means of emery and oil, or pumice-stone and water. From 400 to 500 revolutions per minute. Faulty or chipped pieces may easily be repaired with a hot soldering iron and ambroin cement, or pieces of quality B.A S.

Polishing.—Similar to wood. Shellac polish coloured with aniline dyes. Very little oil should be used.

Threads.—It is stated that male threads can easily be moulded. With female threads a metal nut should be moulded in wherever possible. Male threads may subsequently be cut with a hard chaser, and female threads with a warmed tap, or direct with the warmed screw to be used. The latter should be rubbed with a little oil, warmed on wire gauze over a Bunsen flame, and then pressed and screwed into the drilled hole. In order to fix metal contacts, etc. on to ambroin, wood screws should be used—they hold better, and are more easily fixed than metal screws.

Recent tests indicate that some qualities of ambroin are rather hygroscopic. A $\frac{3}{16}$ piece which was tested broke down at 1500 volts, but after being dried and saturated with Sterling varnish, it withstood 4500 volts. In *Technics* for December 1904, in an article entitled "Insulation and Insulators," Symons reports as follows, on "Ambroin":—

"*Ambroin* is composed of fossil copal and silicates, the silicates being saturated, and mixed with the copal by special process, producing a good non-hygroscopic, strong, homogeneous insulator. A sample, 3·3 mm. thick, broke down with 3500 volts; has a good insulation resistance, but is affected by some concentrated acids and alkalies, and absorbs moisture to the extent of about

0·32 per cent. of its own weight after one and a half hour's immersion in water at 120° F.; is inflammable after flame has been applied some time; is mechanically good; compressive strength.

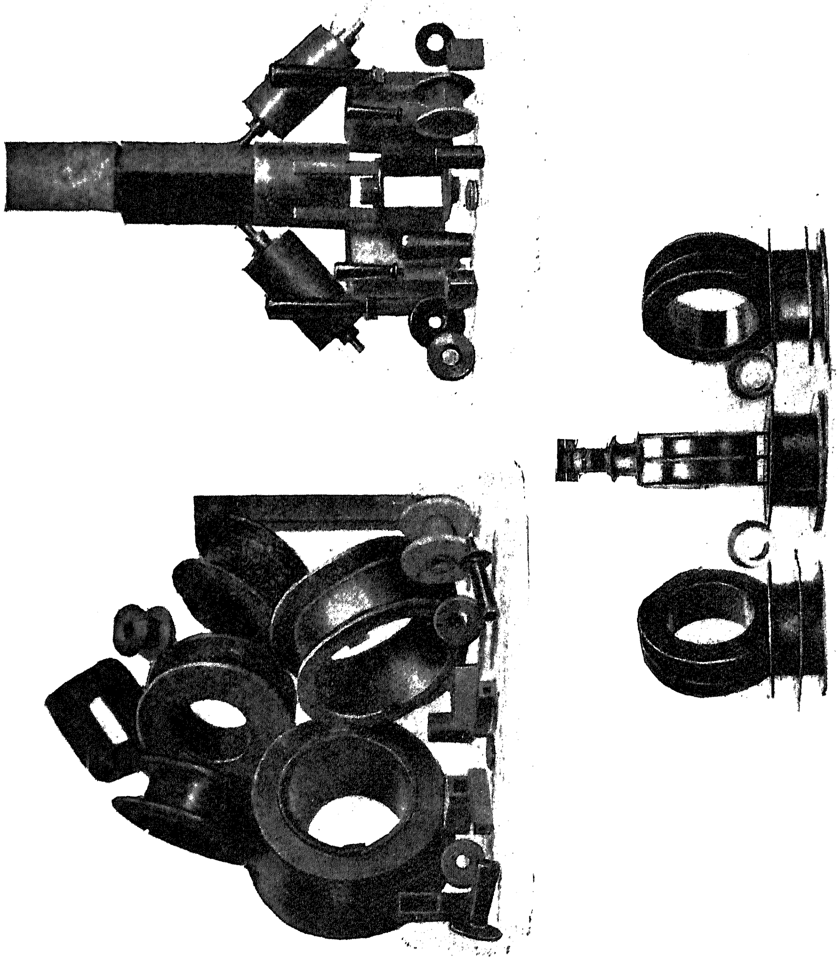


Fig. 62.—Moulded Forms of Psychiloid.

2680 lbs. per square inch; tensile strength, 2140 lbs. per square inch; is, however, inclined to be brittle."

Psychiloid.—This is another material for such purposes. Its base is said to be paper pulp, which goes through several processes of curing and drying, and is finally put through the

chemical vats. This gives psychiloid in the rough, a material which, it is stated, may be machined, sawn, punched, tapped, worked in a lathe, or made up to any required shape or design. It may be obtained in sheets from $\frac{1}{16}$th to $1\frac{1}{2}$ in. thick. Psychiloid is claimed to have great rigidity and strength. A piece of sheet psychiloid 1 inch square by $\frac{1}{8}$ in. thickness is stated to stand a pressure of 25 tons without crushing. Psychiloid is said by the manufacturers of it to be insoluble in ordinary solvents. It is stated to have been immersed for one month in

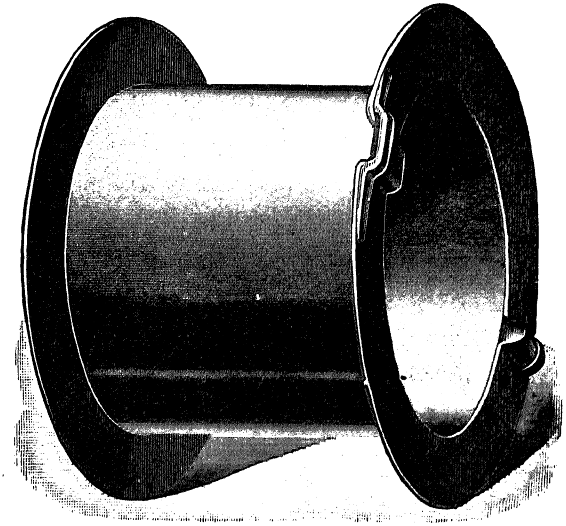


FIG. 63.—Isolit.

water and sulphuric acid (3 : 1) without the slightest effect, and that it can be boiled in water without any sign of disintegration. It is also said to be practically non-absorbent, and to be unaffected by animal, vegetable, or mineral oils. Its manufacturers advocate its use for commutator rings, bushes, and washers, and for formers and bobbins of any required size and shape, and also for square or round tubing in lengths up to 12 inches. A sample $\frac{3}{16}$th in. thick is stated to withstand 20,000 volts.

Some psychiloid insulating parts are shown in the groups in fig. 62.

In Symons' article on "Insulation and Insulators" (Paper read before the Students' Section of the Institution of Electrical

Engineers, April 27, 1904), it is stated that psychiloid has a high disruptive strength. A sample 3·2 mm. thick withstood 25,000 volts, and had a good insulation resistance; it was found to be tough, but inflammable. Symons subjected samples of Psychiloid

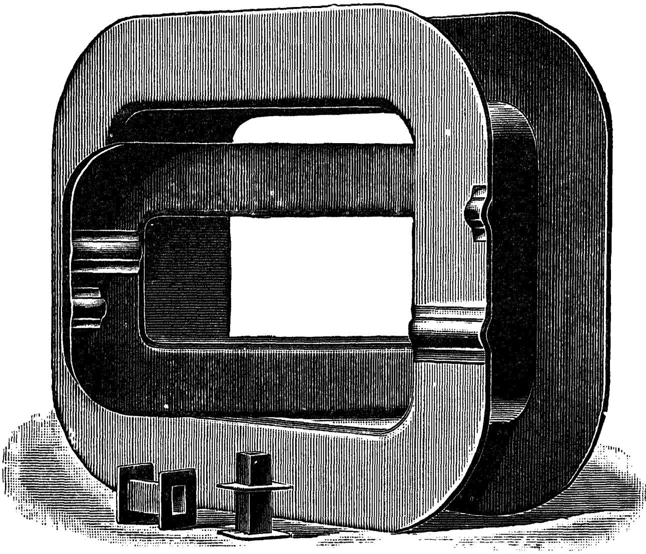


FIG. 63A.—Isolit.

and Litholite [1] to immersion in acid alkali and water for fourteen days at 14° C. with the following results:—

TABLE XXIXA.—PROPERTIES OF PSYCHILOID AND LITHOLITE.

	Sulphuric Acid, Density 1·20.	25 per cent. Solution by Weight of Caustic Soda.	Distilled Water.
Psychiloid . .	Rendered very soft	Entirely disintegrated	Rendered soft, and increased in weight 10 per cent.
Litholite . .	Rendered soft	Reduced to a pulp	Rendered soft, and increased in weight 8 per cent.

"Similar tests on Roburine and Mineralite have produced the same effect as on Psychiloid and Litholite."

[1] For a description of Litholite, see p. 115.

Isolit.—Isolit is a form of papier-mâché, impregnated, and also covered with a special insulating compound. Dynamo bobbins made from isolit are stated to be exceedingly strong, and are also very light. For qualities requiring to withstand excessive heat, special features are employed in the manufacture. The bobbins for continuous-current windings have iron angles embedded at the flanges to increase the strength. This is impracticable for alternating current bobbins, but sufficient strength is, nevertheless, generally obtainable. Some isolit bobbins are shown in figs. 63, 63A, and 63B.

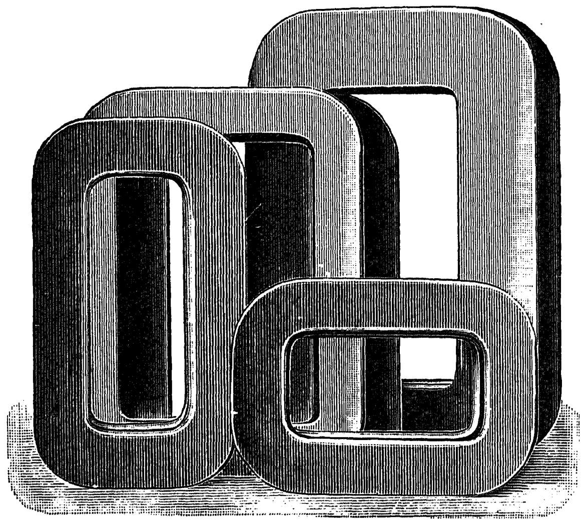


FIG. 63B.—Isolit.

Adit.—Fig. 64 shows a group of Adit bobbins, bushes, flanges, and other parts. The manufacturers classify Adit as a sub-variety of Isolit, and state that it has great strength and is exceedingly tough. It is stated that it tests up to 130 kilos per sq. cm. It can be moulded with sharp corners, and, when necessary, metal pieces can be embedded in it, thus ensuring additional strength at exposed edges and corners. "Adit" is said not to shrink. It is made to exact measurements. In a thickness of 2 mm. it is claimed that it tests up to 1000 volts; 3 mm. to 1800 volts; 4 mm. to 3000 volts; 5 mm. to 4000 volts. It is claimed that it is difficult to ignite, and that it does not continue to burn when the flame is withdrawn. It is further stated to be insensible

to dampness, and to stand heat up to 60° Cent. in some qualities, and up to 120° Cent. in other qualities.

Litholite.—A sample of "litholite" measuring 4·1 centimetres

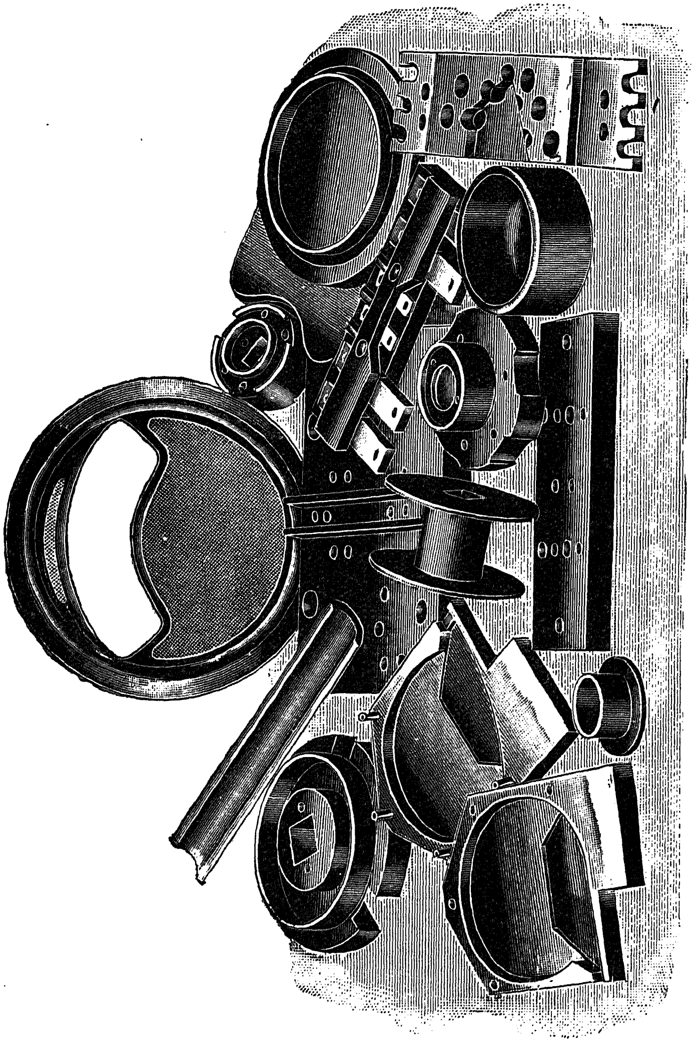


Fig. 64.—Adit.

in thickness was tested between two metal plates, 1 inch in diameter. It is stated to have withstood an alternating pressure of 5000 volts for 10 minutes without appreciable rise in temperature. The pressure was slowly raised to 10,000 volts, and after four minutes' application the material broke down. The time

occupied in raising the pressure from 5000 to 10,000 volts 20 minutes. The temperature of the room at the time o test was 17° Cent. This test was made in June 1903 by Electrical Standardising, Testing and Training Institution.[1]

Vulcanised Fibre.—Vulcanised Fibre is stated to be pro by treating specially prepared vegetable fibre with pow chemical agents, whereby the exterior portion of each sep fibre becomes glutinous, and while in this condition the mass is consolidated under very heavy pressure and bec practically homogeneous. After this, the chemicals are extra the mass is manipulated, rolled, pressed, and cured by va methods, and the result is Vulcanised Fibre. Being an extre delicate chemical process, liable to vary with the different ditions of atmospheric moisture and temperature, it require utmost skill, care, and experience to produce uniformly good re The machinery required for its manufacture is cumbersome costly, and requires to be kept in perfect adjustment at all ti

It is claimed that it is in practice a material of great stre elasticity, and durability. It is stated to be absolutely inso in all ordinary solvents, and to be uninjured by contact alcohol, ether, ammonia, turpentine, naphtha, benzine, petro or any of the animal, vegetable, or mineral oils. It absorbs w both when hot and when cold, but it is not injured the further than that it swells when wet, resuming its origina when dried. Hard Fibre closely resembles horn in its consist is exceedingly tough and strong, resisting an enormous compr strain, and retaining its elasticity at all ordinary tempera Hard Fibre improves by seasoning, and is entirely free from It has a specific gravity of about 1·3. It is made in sheets 42 inches wide by about 66 inches long, and from $\frac{1}{84}$th inches thick. It is also made into tubes of varying in

[1] Symons, "Insulation and Insulators," (Paper read before the Stu Section of the Institution of Electrical Engineers, April 27, 1904), repo follows on Litholite :—

"Litholite has a very high disruptive strength, a sample ·445 cm. withstanding 20,000 volts, and has a good insulation resistance ; is inflam but tough."

With respect to its solubility, reference is made to Symons' te Psychiloid and Litholite, on p. 113.

diameters from $\frac{3}{16}$ths of an inch to about $2\frac{1}{2}$ inches, and larger sizes can be made specially to order. The thickness of the shell depends upon the interior diameter of the tube, running from $\frac{1}{16}$th in. on the smallest sizes to about $\frac{3}{8}$ths of an inch on the largest. Small tubes cannot be formed with thick shells. They are stated to be entirely free from grit, are very hard and dense, and at the same time exceedingly tough and elastic under compression, and it is claimed that they are not in the slightest degree deteriorated by age, but, on the contrary, improve by seasoning. It is stated that it can be worked in a lathe, drilled, riveted, sawed, and punched; can be fitted with sharp, strong screw threads, and receives a fine polish. It is not brittle, and cannot be fractured by a fall or any ordinary blow.

From these sheets and tubes all other forms must be produced by ordinary mechanical methods, as Vulcanised Fibre cannot be successfully moulded at any stage of its manufacture.

It is an excellent insulator in all dry positions, and is often used as a substitute for hard rubber.

It has been used in dynamos for commutators, magnet heads, etc.

Owing to its remarkable toughness and strength, which admits of its being forced into all sorts of positions without liability of breakage, the ease with which it can be tapped, drilled, and screw-threaded, and the firmness with which it holds screws, it is claimed that it is far superior to rubber or any material for most of these uses. The insulating properties of Vulcanised Fibre have been found satisfactory for many purposes. As it is much cheaper than hard rubber and similar materials, and improves with age, it is often economical to use it. It is made in three colours, red, black, and grey. It is susceptible of a fine finish. Tubes are from 22 inches to 36 inches long. Hard Fibre is said to possess great tensile strength, and to sustain great weights without being crushed or injured.

Roburine.—Another material of this group is called "Roburine." Symons[2] reports that Roburine can be moulded, is tough, has a

[1] "Insulation and Insulators." H. D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.) With respect to Roburine, Mineralite, Psychiloid, and Litholite, Symons states his opinion that "they are of little value as insulators, the only use to which they could be put being for bobbins or switch handles; they are, however, cheap."

fairly high disruptive strength and a good insulation resistance, but, like most of the materials in this group, it is inflammable, and, like them, is not insoluble.

Mineralite.—Symons reports that Mineralite has high disruptive strength, is extremely tough, and will withstand high temperatures, but that it also is soluble.

Aetna material.—This is used chiefly for strain insulators. The results of Symons' tests upon samples of "Aetna" material are as follows:—

Aetna.—Used for strain insulators. The following is the result of tests carried out on an Aetna strain insulator: Puncture resistance, 11,000 volts; insulation resistance, 20,000 megohms; tensile strength, 2·46 tons; a sample immersed in water at 120° F. absorbed 3·17 per cent. of its own weight in one and a half hours. Will withstand great heat without disintegration, but is inclined to be brittle.

For the following compilation of interesting particulars regarding various miscellaneous substances of this group, the authors are indebted to Symons. "Insulation and Insulators," H. D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.)

Paraffin Wax.—Will increase the insulation resistance of fibrous materials, but is very inflammable. It is acid- and waterproof. When mixed with linseed oil it forms an impregnating insulating material of high disruptive strength.

Ebonite and Vulcanite.—Types of hard rubber; have very high disruptive strength, Ebonite $\frac{1}{40}$th of an inch puncturing at 21,000 volts; they are brittle, however, and the surface is affected by exposure to air.

Bitumen is a most excellent insulating material, but owing to its low temperature limitations (it flows freely at a little above 100° Cent.) it has not been employed in dynamo-electric machinery; it has a very high disruptive strength, $\frac{1}{10}$th of an inch puncturing at 30,000 volts, and a good insulation resistance. It is chemically inert, and does not perish so quickly as coal tar pitch.

Coal Tar Pitch has much lower puncture resistance than bitumen, $\frac{1}{10}$th of an inch puncturing at 5000 volts; it has a lower insulation resistance, and is brittle.

Asphalt has been made a commercial success for cable conduits; has the advantage that it is unaffected by water; is very ductile; and can be easily and cheaply repaired.

Slate.—Must contain no metallic veins, and should be enamelled to render it less likely to absorb moisture.

Porcelain.—Much cheap porcelain is hygroscopic, and depends on the glaze for its insulating properties; the best shows a vitreous fracture if chipped. A simple test to show the quality of porcelain, is to chip the surface, and a poor quality will show a flowing stain from ink. The best qualities have high disruptive strength and insulation resistance, and are unaffected by exposure to climatic conditions.

Glass[1] has a very large surface leakage; is also slightly soluble in rain water, which roughens the surface, dirt accumulates, and reduces the insulating qualities; it is, however, superior to much cheap porcelain, but has the disadvantage that it is cracked or shattered by a blow, whereas porcelain is only chipped. Flaws are, however, readily discovered in glass by inspection, whereas, in porcelain, insulation tests are generally necessary to disclose them.

Under date of December 18, 1903, Mr W. S. Moody, of the General Electric Co. of Schenectady, U.S.A., contributed a most interesting paper, entitled, "Terminals and Bushings for High-Pressure Transformers," to the *Transactions of the American Inst. of Electrical Engineers.* His remarks on the insulation of main high-pressure terminals and leads are of such great interest that we propose to quote them at considerable length.

"Below 40,000 volts the insulation of terminals offers no special difficulty; porcelain or glass bushings can readily be obtained that are safe for this pressure, even if the conductor has no insulator covering. For higher pressures the problem is more

[1] Gray and Dobbie have found (*Royal Soc. Proc.*, lxvii. pp. 197–207, October 31, 1900) "that potash glasses have very much higher resistances than soda glasses. In one case the substitution of soda for potash in the composition of the glass was found to diminish the resistance of the glass to $\frac{1}{130}$th of its former amount. It was found that the effect of annealing glass is very greatly to increase its specific resistance. In the case of lead-soda glass, the specific resistance was raised to three times its former value. Annealed glass is therefore a much better insulator than unannealed glass."—*Sci. Abs.*

difficult; if no insulation is used on the conductor, the bushings become expensive and so large that there is scarcely room on top of a moderate-sized transformer for as many terminals as are often required. The following are some of the more common forms of bushings that have been used:—

Wooden tubes;

Hard-rubber tubes;

Glass and porcelain tubes, both single and concentric;

Numerous forms of moulded porcelain bushings.

"Wooden tubes of the necessary size cannot be thoroughly dried and filled. Hard rubber is so apt to contain impurities that it is unsatisfactory; moreover, it deteriorates rapidly if ozone is generated near it. Glass is fragile and must be protected with other semi-insulators. Porcelain, or any smooth tube, must be very long if it have sufficient leakage surface to be safe when dirty, and even the best shapes of corrugated bushings are large and expensive when capable of withstanding a test of from 75,000 to 160,000 volts.

"All things considered, the writer has found the following practice quite satisfactory for test pressures not exceeding 160,000 volts.

"Insulate the lead with varnished wrappings that will safely withstand for one minute about half of the test pressure to be applied, bringing out this lead through a porcelain bushing having the same strength as the insulation of the lead, and sufficient surface to prevent leakage at this pressure when dirty; in other words, let the insulation of the leads be sufficient for the working pressure and the porcelain be of such strength as to give the factor of safety desired. This combination forms a far safer insulation than a bare conductor and a larger bushing which would stand the same puncture test as the combination, from the well-known fact that oxidised linseed oil is an insulation that will momentarily stand several times as much as it will for any considerable length of time, while porcelain, glass, etc., have no such time factor.

"In leads requiring a test of 100,000 volts or more, and insulated in this manner, an additional difficulty is met in the induced charge on the outer surface of the insulation; at this pressure the surface is covered with a heavy brush discharge that so

reduces the surface resistance to leakage that 100,000 volts will travel along several feet. It is usually impracticable to make the insulated lead long enough to withstand the pressure under these conditions, but the discharge may be broken up, so that it will not appreciably reduce the surface resistance, by bell-shaped pieces of rubber, porcelain, or other insulation slipped over the lead before all the varnished wrappings are put on, and having its small end so shaped as to allow of its being buried in the outer wrappings.

"In transformers designed for Y-connection and grounded neutral, some transformer builders, in order to save expense on high-pressure bushings, have grounded one terminal on the case and insulated only such leads as are to be connected to the line; this prevents operation with Δ-connections, but otherwise seems unobjectionable. In similar manner, the use of three-phase transformers, with the inter-connecting between the phases made within the case, reduces the expense and possibility of trouble with bushings."

Lava.[1]—"The material now so well known as 'lava,' through its universal use in the manufacture of gas tips and burners and its widespread applications in the electrical arts, is not, as is frequently supposed, a natural product of volcanic origin. It is the mineral talc (H_2,MG_3,SI_4,O_{12}), which is machined in its natural condition, and then baked under certain conditions of time and temperature (about 2000° Fahr. or 1100° Cent.) to a condition of such extreme hardness that when properly kilned it can scarcely be cut except by diamond.

"The material, being baked as stated at a temperature of about 2000° Fahr., is unaffected by any subsequent temperature short of that heat, and therefore by any heat to which it may be exposed when used in the construction of arc lamps, rheostats, electric heating apparatus, etc., etc.,—in fact, under any conceivable circumstances a lava insulator would withstand a far greater heat than the conductor which it protected.

"It fuses with difficulty under a strong blast flame, and has no superior in withstanding the electric arc. It is only slowly dissolved by hydrochloric acid, and is not affected at all by other

[1] These particulars concerning lava are compiled from a publication of the American Lava Co.

acids or by alkali. It is absolutely free from metal oxides or other impurities which would impair its insulating value. It is permanent in constitution, and being a natural product is not subject to variations in structure or composition. It neither swells nor shrinks with changes in atmospheric moisture, and its coefficient of expansion with temperature being negligibly small, it is of especial value in instruments requiring a fixed relation of their parts under all conditions.

"The material before baking is sawn, milled, drilled, turned, and threaded with the same freedom as metals such as brass, and by tools of the same character. Lava products are produced with the same degree of accuracy and interchangeability as those of a screw machine, and without the necessity of first making dies or moulds.

"For most work and for pieces of bulk the method of baking is much the same as with porcelain, where coal or coke ovens are used; while with pieces of moderate size, and especially where close control of temperature is desired for the purpose of extreme accuracy and uniformity, the electric furnace or gas-blast furnaces are employed.

"With respect to accuracy, from the method of working, highly satisfactory results are obtainable. For a kilned product it is stated that lava offers unusual advantages in respect to uniformity, and is much superior to porcelain in this regard.

"The American Lava Co., of Chattanooga, Tennessee, U.S.A., has made many tests for dielectric strength with transformers of large capacity and carefully calibrated electrostatic voltmeters. These tests are stated to have demonstrated that lava is remarkably uniform in its ability to withstand high potentials, not only momentarily, but when continued indefinitely, as its "dielectric hysteresis" and surface creepage loss cause no more heating under continued stress than in the case of porcelain under the same conditions. Its dielectric strength may be expressed as from 3000 to 10,000 volts per millimetre thickness, depending, as in the case of all other electrical insulators, upon the absolute thickness of the sample tested. The diagram in fig. 65 will give a better idea of its insulating properties.

"The cut represents specimens of lava and glazed vitreous porcelain in half size, and shows the metal surfaces between which

high potential was applied; the outside bands of tinfoil having been reduced in width by many trials until the potential would puncture the insulation instead of discharging through the air and over the ends of the specimen. The potentials indicated are mean effective voltages, alternating current (*i.e.* R.M.S. voltages). The insulating resistance of lava samples of the shape shown, and with similar electrodes, it is stated, has always been found to be not less than 30 megohms under ordinary atmospheric conditions. It will be seen from the figures given that both the dielectric strength and insulation resistance of lava are amply sufficient.

"Since lava is acid proof and superior to porcelain and glass in heat-resisting qualities as well as in strength, and since it may be

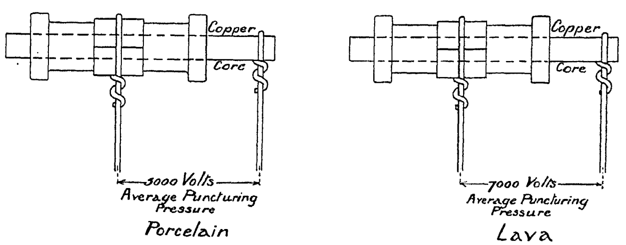


FIG. 65.—Comparative Tests of Lava and Porcelain.

turned cheaply in moderate quantities without the cost of dies or moulds, it is for many purposes the most practicable of the materials possessing any of the above qualities, while no other material now in use combines them all. As compared with wood, horn, fibre and compositions of rubber, etc., etc., it is stated to be frequently cheaper and always better. As compared with mica, lava lends itself to a large variety of shapes in which mica cannot be employed.

"Improvements and economies in lava working have kept pace with the times, with the result that the price of lava is stated to have now reached a point where it competes with most of the commoner insulating materials."

CHAPTER VII

THE INSULATION OF COMMUTATORS

In selecting a suitable material for commutator insulation, one should remember first of all that no part of the whole machine is so liable to give trouble as the commutator, and its condition is in most cases a fair index to the machine's condition.

The requirements for the insulation between segments are that the insulations must be—

I. Extremely compact and firm, yet not too hard in texture.
II. Uninfluenced by heat.
III. Of uniform thickness.
IV. Incapable of absorbing moisture and oils.
V. Of good insulating quality.

It has been the general conclusion, after experimenting with different materials, such as cardboard, fibre, asbestos, leatheroid, and mica, that none fulfilled these requirements as well as the last named. But even then one must discriminate, and employ only the most suitable quality of mica.

For segment insulations, some firms have used several leaves of whole mica cut to the dimensions of the segment, these being assembled dry without any varnish to hold them together. The writers would not recommend this plan. If it is adopted, one must select the softest mica obtainable, so that its rate of wear will be at least as great as that of the copper, otherwise the insulations will ultimately project slightly above the surface and prevent the brushes from making constant smooth contact with the copper, thereby causing sparking and blackening of the segments, and necessitating frequent turning, sand-papering, and truing. This method of construction has the disadvantage of high cost, as the

waste trimmings from cutting the mica to the required dimensions have little or no value, so that the method is in many cases too expensive to be permissible.

Another method consists in pasting together in layers, mica which has previously been split into very thin small pieces, the object of splitting being that the laps will make no appreciable difference in the thickness per layer. Shellac, copal varnish, and various compounds are used for sticking these bits together, but the sticking medium should be thinned and sparingly applied, as the plate which has been built up in this fashion must be pressed and heated (preferably at one operation) to expel from the plate all but an extremely thin film, only just enough to hold the components together. The plate thus formed is then sawed or sheared slightly larger than the commutator segment. It is afterwards again heated and pressed, and is finally put through a milling machine which grinds it to the proper thickness. The plates must be of extremely uniform thickness, a variation greater than 0·05 millimetre not being permissible.

After assembling the insulations and copper segments in the press ring, they must be again heated before or during the pressing operation, so as to squeeze out all surplus sticking varnish, and to firmly press the copper and mica segments together into a compact structure. This completes the most exacting part of the process. Green or amber-coloured mica should preferably be used for the insulation between segments, as these are the two softest grades, and it is well to repeat that great care should be taken to exclude all unnecessary sticking varnish.

The cylinder and end-ring insulations may be made up of any good quality of mica, for the difficulties are chiefly of a mechanical nature, the thickness required for mechanical strength being greatly in excess of that which would be required for suitable insulation. The mica is split fine, and is afterwards pasted together, either into rings of the proper dimensions or into a semicircle, which is afterwards bent to shape, and the joints broken and matched. This is then formed in a mould and heated, or is placed directly in the commutator, which itself acts as a mould. The former method is much to be preferred, in spite of the greater expense. The secret of obtaining the

best results is in the application of heat whenever pressure is used. This facilitates the exudation of all sticking varnishes and of all moisture, and assists in making the structure compact and solid. It must, however, not be carried to such an extent as to carbonise the shellac, for in that case any oil in proximity to the mica insulation would be absorbed, and thus lead to disintegration of the mica plates.

We have referred to the imperative necessity of employing the softest mica for the insulation between segments. It may be said that the cause of the great majority of the defects developing in commutator insulations is attributable to oil. This subject has certainly never received the attention which it deserves. When really necessary to employ some commutator lubricant, vaseline or paraffin should be used. Oil should never be permitted. Thrust collars and bearings should be so shaped that no oil can escape beyond the confines of the bearing boxes. A drop of oil on the commutator to-day will not at once lead to any difficulty, but in time the oil mixing with the fine copper and carbon dust, and carbonising under the influence of the heat caused by the current and by the brush friction and the sparking, will have its effect. A spot here and there on the commutator will ultimately be seen to glow intermittently, and will eat its way deeper and deeper, in many cases without being discovered, and in the process of time it will have covered enough area to set up a high resistance leak between some two segments. This continues, the segments sometimes finally becoming blue from the heat, and sometimes the coil breaks down through the heating caused by the leak between segments. In some such cases, when the trouble has been located in time, further trouble has been avoided by carefully scraping out the injured insulation and filling up the cavity with a heat-resisting plugging.[1] To do this successfully is a by no means easy matter.

[1] Silicate of soda, mixed with fine mica dust so as to form a paste, plugged into the crevice, answers the purpose.

CHAPTER VIII

.TING VARNISHES, PAINTS, AND IMPREGNATING MATERIALS

ING varnishes are employed to improve the initial insulating
›s of papers, fabrics, and fibrous materials which are im-
d with them, and to maintain the constancy of their
.sulation resistance.[1]

ie varnish embodies all the desired properties. It is
y to have a knowledge of the good and bad qualities of
varnishes. For most purposes an insulating varnish

[1] upon this last function, namely, that of maintaining its constancy,
ngton lays stress :—

: primarily necessary for us to define the exact function of a varnish
the coils or windings of a dynamo-electric machine. Why should
be used at all? Solely because there has never been an insulating
uced which did not need some sort of reinforcement, which could
be best applied in the form of a paint or varnish. Motors will not
in very dry situations, unless some protection in the shape of
: applied. We asked electricians for an explanation of this; they
ıt water got into the machines if varnish was not used. When this
ıs applied to street railway motors running on submerged tracks,
›rs unprotected from street spattering, the explanation seemed to be
but its adequacy was completely lost when we applied it to
machines, running under fairly good conditions.

' the insulation resistance of the varnish is not required to enable
ine to run. There probably never has been a successful machine
wherein the difference of potential between turns was equal to 10
of the insulation resistance of the ordinary double-cotton covering
s used on those turns. This covering has an insulation resistance
ıbout 200 volts alternating current, and it is obvious that if that
could be made constant there would be no necessity for the rein-
of machine insulation with anything in the line of paint or varnish.
words, any paint or varnish which is used on magnet coils is used
ıe of making constant the initial insulation resistance of the cotton
—Franklin Inst., March 12, 1903.

should give a permanent and thoroughly uniform coating of insulation which will not become brittle, crack or peel off through the influences of heat, age, and ordinary service. It should be plastic, and should not flow at any temperature below 200° C. It should not cause corrosion; and its mechanical strength should remain constant. Neither water, acids, nor oil should affect it. It should be as cheap as practicable. Sometimes one insulating varnish may be mixed with another, and far better results obtained than by using them separately, but to employ such methods with success requires much experience, and a knowledge of the composition of the component varnishes.[1]

[1] "Taking first 'paints or varnishes,' we find the following features desirable, if not absolutely essential:—(1) They should be quick-drying, and yet should not lead to great waste owing to the drying up of the solvent; (2) they should have considerable elasticity and strength; (3) have a high melting-point, and should not lose their insulating properties or char with possible rises of temperature in practical use; (4) should not chemically affect the copper conductors; (5) must be waterproof and unaffected by oils, acids, and, as sometimes specified, salt water; (6) last, but not least, should be good insulators."—"On Insulation," *Electrical Engineer*, September 16, 1904, p. 411.

The following note from *Science Abstracts* is useful in connection with this subject:—

Insulating Paints—Toch.—"A brief article on electric insulating paints. The materials employed in the manufacture of insulating paints and varnishes consist principally of resins in a suitable solution. The addition of a metallic element would be decidedly harmful. The principal gums that are used in making insulating varnishes are resin, asphaltum, pitch, tar, kauri, manilla, shellac, and copal. The principal solvents are turpentine, benzine, benzol, acetone, alcohol, bisulphide of carbon, linseed oil, china-wood oil, and in some instances water. Resin is very largely used as a gum, but in very fine work a solution of resin alone is rather dangerous."—*Electrochem. Ind.*, December.

The manufacturers of "armalac" refer to *three* materials for use on magnet wire, namely, paints, varnishes, and insulating materials. In one of their publications they state:—

"Varnishes and paints are chemically and mechanically defective for protecting and reinforcing the insulation of the cotton covering of magnet wire, so that it shall not absorb moisture, dirt, and copper oxide and thereby lose its insulating power. But absolutely infallible *insulating material* can readily be obtained. True, *insulating compound* must have an initial resistance of 1000 volts for each 0·001″ in the thickness of the film, measured by one minute strain at 70° Fahr. Many varnishes and paints give a better initial resistance ––– the above, and this leads electricians to overlook mechanical defects 1 quickly render them wholly useless, and chemical defects liable to uestroy all insulation in contact with them.

"A good initial resistance is not more necessary than is permanency of

In the earlier days, shellac varnish (gum 'lac' dissolved in alcohol) was widely employed in the insulating of electrial machinery. It has the faults of softening with moderate heat, of being rather hygroscopic,[1] and of powdering under the influence of age and of excessive heating.[2] It has long since given place to more suitable varnishes. There are now a large number of firms engaged in the manufacture of insulating varnishes. One of the earliest firms to enter this field brought out Sterling Varnish, which enjoys a wide use. It would appear that the materials now supplied under that name are considerable improvements upon the original varnish placed on the market.

Sterling Varnishes.—I. Sterling Extra Insulating Varnish is a heavy bodied varnish, and appears to be composed mainly of concentrated linseed oil and turpentine, and probably also contains a small amount of resin. It has an exceedingly high and uniform insulation strength, and gives a tough but flexible and elastic coating. It is claimed to be impervious to the action of water and

insulation, durability of protective capacity, and chemical stability. Armatures are not the place for chemical transformations.

"To make 'insulating varnish' or paint is an easy matter, but for absolutely infallible insulation the electrician must look to the chemist with knowledge of electrical work, to the chemist whose practical experience as well as technical knowledge enables him to definitely locate and overcome the actual obstacles, to the chemist who will brush aside old habits and ideas and attack the problem with *modern methods*."

[1] "Shellac can only be made into a successful varnish by dissolving it in alcohol, or alcohol and water. You can make a shellac varnish totally devoid of water, but you cannot do it commercially; and if you could, you could not keep it so, as the alcohol in shellac varnish rapidly attracts moisture the moment it is exposed or applied." Farrington.

[2] "Shellac, which is the purified form of 'stick-lac,' is the product of an insect which deposits its eggs on the branches of certain trees in India. These masses of eggs are collected, enclosed in canvas bags, and heated; the liquid which may then be squeezed out of them forms a crude shellac. Shellac varnish is prepared by dissolving shellac in methylated spirit."—*Electrical Magazine*, vol. ii. p. 178.

"Shellac is a compound of vegetable resin acids toughened by insect wax. Dissolved in alcohol it makes a rapid-drying varnish. As shellac is very brittle, it is quickly ground to powder by the vibration of a coil, and its insulation and moisture resistance are quickly destroyed. The action of the resin acids of shellac on copper wire is to form the green discoloration of copper salts which impregnate the cotton covering and destroy its insulation."

From a publication of the manufacturers of "armalac."

oil.[1] It is generally applied to fabrics or paper, and the process should consist in giving the material a thin uniform coat of the varnish, either with a brush or—and preferably—by immersing the material in the varnish until it is completely impregnated. It should then be suitably hung up by one edge until the superfluous varnish has dripped off.

Afterwards it should be baked in an oven at from 60° to 80° C., and if a vacuum oven is employed, air must be admitted from time to time, in order to oxidise the varnish to a hard, dry surface. Baked in a vacuum, it remains soft and sticky, hence the admission of air is essential. According to the thickness of varnish required, the material should be repeatedly immersed in the varnish, and baked after each immersion. If the solvent is allowed to evaporate, the varnish becomes unsuitably thick for obtaining the best results. On shipment from the Sterling Varnish Co.'s factory, the varnish has a specific gravity of 0·90. It should be maintained at from 0·87 to 0·90, by thinning it from time to time with petroleum-benzine.[2]

Besides the Sterling Extra Insulating Varnish, the Sterling Varnish Company supply other grades, which they state to be based on this varnish as a standard, with certain properties accentuated, as shown by their names.

II. The Sterling Quick-Drying Insulating Varnish is claimed to be quick-drying and elastic, to resist oil, to yield a uniform coat of uniform insulation, and to save a great deal of time in the shop for drying.

III. The Sterling Elastic Insulating Varnish is stated to be suitable for work where extreme elasticity and long heat resistance is required. It is stated to have good insulation, and to resist oil and water. It is further stated that it "will stand the heat of the baking oven for 60 days without injury, ensuring the permanency of insulation of coils in overloaded machines."

[1] It will be seen from the footnote on the following page that this claim is very emphatically disputed in some quarters.

[2] "It is not advisable to use too thick a varnish, as the solvent will enter the pores of the material, leaving the dissolved portions on the outside, and on drying the solvent will evaporate, and the disruptive strength will not be much improved, as it will still be hygroscopic, and likely to absorb moisture." —"Insulation and Insulators," H. D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.)

IV. Sterling Black Plastic Insulator. Of this variety, which has only recently been placed on the market, rather strong claims are made, from which the following are quoted :—

"Permanently plastic, oil and water proof, water-repellent, high insulation. This is the only insulating material made that is plastic, permanently elastic, and oil and water proof." "It is permanently plastic under high heat or overloading conditions, and does not deteriorate in any way; the fact that it will stand uninjured 100 days in the baking oven at 85° C. (190° F.) ensures these results. Insulation 1500 to 1800 volts per 0·001". Particularly adapted to armature and field coils in machines which are subjected to heavy overloading."

A fault sometimes found with linseed oil varnishes is that the acid in the oil corrodes the copper of the windings.[1] This action is

[1] Farrington is strongly opposed to linseed oil varnishes. His views upon this subject, as given in his Franklin Institute paper ("Defective Machine Insulation"), may be gathered from the following extracts:

"Determining that the best insulating material must be the one which would reinforce the weaknesses of cotton, we assembled all the materials commercially available for the manufacture of compounds which might be applied to coils of copper wire by dipping or with a painter's brush, and began the work of systematic search for the qualities which would enable these materials to accomplish the necessary results. In this connection every varnish gum, every treatment of drying oils, every combination of waxes, pitches, asphalts, and gum substitutes, including the cellulose compounds, were brought under our tests.

"The first test of all was to see whether a material had a melting point or a viscosity, or a combination of both, which would enable it to stay in a badly overheated coil.

"The tests to determine the capacity of a given insulating material to exclude moisture from the coils of an idle machine were chiefly a process of elimination, and here we found aid from the experience of varnish and paint manufacturers, and in the researches which have been made concerning the materials which enter into their products.

"We first eliminated shellac, for the reason that it could only be made into a successful varnish by dissolving it in alcohol.

"The copal varnishes and asphalt varnishes were eliminated at this point, as we found that the heat and vibration of magnet coils quickly reduced them to a powder, or cracked their films so badly that they could not exclude water any more than a sieve could hold it.

"For some time we thought that linseed oil might be so boiled that it would effectively exclude moisture. We were attracted by its high initial resistance and the extremely tough film which could be obtained from varnishes composed of it, but here again we were stopped by the accumulated facts

liable to occur in cases where the cotton insulation on the wire is not first carefully dried out. It is sometimes maintained that the first thin layer of green corrosion protects the copper from deeper

which experienced varnish and paint makers furnished us. Linseed oil is a commercial commodity solely because of the rapidity, as compared with all other oils, with which it absorbs oxygen. A method of arresting the oxidation of a film of linseed oil at any desired point would be of immense value to the electrical fraternity. We cannot hope to arrest the oxidation of a film of linseed oil at any particular point. It continues to oxidise until it becomes a brittle, cracked, and utterly defenceless mass, so far as its capacity to prevent the passage of any stray electric current is concerned. More electrical apparatus have been reconstructed or repaired because of the oxidation and other defects of linseed oil than of all other causes put together.

"A great many electricians like to claim that their apparatus is well ventilated. 'Well ventilated' also means 'well oxidised.' There are very few armatures which are not 'well ozonised' also.

"When the wearer of a black coat leans against the white trimmings of a house which was painted with linseed oil and white lead last spring, he has to dust himself off, simply because the oil which should have held the pigment to the house has been totally destroyed by atmospheric action. It is because of this quality of linseed oil that we are compelled to have a varnishing day in our art galleries; and it has never been disputed that thoroughly oxidised linseed oil is not only soluble in water, but is hygroscopic, since that fact was established many years ago by eminent German authorities.

"We had to consider that an insulating compound might be used some day, in a generator located on top of a steel penstock in an isolated power-house where there was no heat, and that when the generator should shut down, it would attract moisture at a tremendous rate by condensation. It would not run a week under these conditions if it were insulated with a linseed oil preparation. It is well known that a series of chemical actions may take place in an electrical machine, wherein linseed oil may be found wholly responsible for the presence of water even before the oxidation of the oil has reached the advanced stage. This occurs when an atom of hydrogen in the oily acids of the varnish is replaced by an atom of copper. The ejected atom of hydrogen selects a pair of friends from the oxide on the wire and thus produces water. Only one material was able to pass these tests for the exclusion of moisture under practical conditions, that being the high melting-point paraffin compound, whose widely successful use has brought to me the honour of delivering this address.

"A particular point which led us to the adoption of this material is its capacity to withstand high temperatures for a great length of time and still maintain its original plastic condition. The vibration in a high-speed armature probably equals that in any mechanical device when the shattering jars of gear connections are taken into consideration, and when street railway machinery is added to the list of apparatus under consideration.

corrosion, and that the occurrence is thus practically harmless, and the more so the larger the diameter of the wire. Another fault alleged by the critics of these varnishes is, that lubricating oil acts

"The expansion of armatures and field coils as they heat, and their subsequent contraction when the loads are removed, are obvious, and consequently any insulation which does not have permanent plasticity under heat is wholly defective for this sort of electrical insulation. Consequently a large list of materials composed of varnish gums and linseed oil, asphalts, etc., were eliminated one by one as they showed their utter incapacity to stand the shattering influence of this vibratory stress.

"The defectiveness of the first material which we ever made was caused wholly by the presence of varnish acid. As is well known to varnish chemists, all of the varnish gums are acid bodies. Indeed, it is safe to say that there is practically nothing in the shape of gum or oil which enters into varnish that is not an acid body. The question then arose, 'How far is anybody warranted in introducing acid into the vitals of high-cost apparatus?' Of course the answer is, 'Just as little as possible'; but I am sorry to say that a good many electricians have declined to give this point the consideration to which it is entitled, and they have thereby become responsible for a great deal of the apparatus which has proved defective. Of course I am familiar with the claim of some electricians that they 'never have any trouble with apparatus built by them.' In the first place, we know that such a statement is not true; and if it was true, it would not be a good reason for deliberately disobeying physical law.

"The obvious unfitness of linseed oil for motor insulation, because of its acid composition, is best explained by reference to indisputable authority. What everybody knows 'is most indisputable authority,' and anybody who knows anything about chemistry knows that an acid is a body which will attack metal. An acid is a body which attacks copper. An acid is a body which will combine with copper to produce a third and possibly a fourth material. Users of shellac, copal varnish, and linseed oil varnish as insulation have frequently found that the cotton covering of their wire has been turned a brilliant green, which is a universal symptom that the copper has been attacked by an acid. When we said that such a symptom was a bad one, some electricians argued with us, and said they didn't think we had any authority for that statement, and that it didn't make any difference if a coil did turn green, provided that coil was properly baked out. They declined to accept what every chemist knows. We have given considerable thought to this matter, and have come to the conclusion that a green coil is an evidence of bad construction, is *prima facie* evidence that a radical chemical change has gone on within precincts whence chemical changes should be excluded with great rigour."

The authors, however, wish to point out that it is an indisputable fact that linseed oil varnishes are in far more extensive use in the manufacture of dynamo-electric machinery than all other varnishes together. Furthermore, their intelligent employment has been demonstrated to be consistent with the very highest class of products in this line of manufacture.

deleteriously upon linseed oil, and upon insulations impregnated with linseed oil varnishes.[1]

However this may be, a number of other varnishes have been placed on the market, for some of which it is claimed that these particular faults have been overcome. This is doubtless a fact in the case of at least one of them, namely, armalac, for in this

[1] "Affecting the copper winding chemically applies more particularly to varnishes, but as insulating materials are generally secret mixtures it is not safe to say that all paints are free from this fault. If, however, care is taken to neutralise any acids, such as would attack copper and give us the green deposit of copper sulphate, this fault is done away with. The moisture in the cotton covering of wires, not dried out before varnishing, assists in this chemical action which destroys the cotton covering, and thus leads to short-circuiting of the turns."—"On Insulation," *The Electrical Engineer*, September 16, 1904, p. 412.

"Amongst the obstacles to the insulation of armature coils, etc., are:—Firstly, the moisture and acid in the cotton wire covering. Nearly all the moisture and some of the acid can be driven out by baking the coils and treating them with insulating compound while they are yet hot. But the compound must prevent the re-entrance of moisture. It must do this mechanically by permanently hermetically sealing all pores. It must do it chemically also. The last sentence explains the defective insulation of linseed oil and compounds containing it, as oxidised linseed oil is hygroscopic (*i.e.* absorbs moisture). True, insulating compound must permanently arrest the action of the acids of the cotton. Varnishes cannot do this, being themselves readily acted upon by those acids.

"The second obstacle is the susceptibility of copper to the action of oxygen and weak acids. The copper oxide or 'salts of copper' thus formed are rapidly absorbed by the cotton, and its resistance is thereby destroyed.

"It is a sad mistake to think that the green discoloration of cotton, paper, or mica is of no consequence, because tests show them to still have quite a good insulation after the discoloration has taken place. For such tests are made long after and under very different conditions than those operating when that chemical action took place, and even then they show that the insulation is radically decreased.

"When that chemical action took place, there was little or no insulation at all. A varnish solution of copper is not good insulating material, and at the time the action takes place gases may be formed which are good conductors of electricity.

"Every care should be taken to keep acids out of the copper vitals of electrical apparatus.

"These points are too well known for comment, further than to express astonishment that electricians do not take them into consideration. The copper oxide frequently penetrates thick paper and other mechanical insulation, destroying their value."—From a publication of the Massachusetts Chemical Co.

varnish a material of entirely different character is employed, namely, paraffin wax. It is stated that armalac is black paraffin wax in solution in petroleum naphtha, the melting point of the paraffin being permanently raised by a secret process. It is claimed for the compound that while its melting point is over 300° Cent., it never becomes hard and brittle on an armature, that there is an entire absence of any traces of resin acids, and that all possibility of any formation of salts of copper is excluded. Armalac is said to absorb all lubricating oil which may enter into it, and it is claimed that its insulation resistance is not thereby impaired. It permanently retains its plastic nature, but it nevertheless dries quickly and thoroughly. It is claimed that its initial insulation is also permanent. In appearance, armalac resembles a quick-drying asphaltum paint. It is stated to be a perfectly homogeneous compound, containing no sediment and undergoing no chemical change, either in the liquid form before use or after it is applied. The solvent rapidly evaporates, leaving a dry but plastic film behind it.[1]

[1] The manufacturers of "armalac" rest a considerable proportion of their claims for the material on its alleged "friendliness" to lubricating oil. In one of their publications they make the following statements:—

"The constant presence of lubricating oil has been erroneously thought to be a cause of short circuits. No compound should be used whose chemical nature will be affected by combinations formed (under the heat of the machine) with lubricating oil. (The latter is a good insulator always.) Varnishes (composed of groups of vegetable or resin acids) release free resin acids when forming combinations with other oil, and it is the free resin acid so produced which causes the short circuits commonly attributed to lubricating oil.

"A true insulating compound will take up all the oil that comes to it, and its insulation and durability will be reinforced thereby.

"Oxidation is the worst enemy of an armature. 'Well-ventilated armature' means 'subjected to constant oxidation.' A true insulating compound will keep oxygen off the copper. A varnish will carry it in until chemical laws are repealed.

"A true insulation will carry neither free acids nor acids in a combination liable to be subsequently broken by working conditions. There is no varnish known to commerce to-day which does not show this defect when applied to the copper vitals of high-cost machines. 'Armalac' is the trade-name for a black paraffin with a melting-point far above the actual requirements. It is impervious to moisture and oxygen, strongly resisting all acid action, and shown by eight years' test to remain permanently plastic under heat. It is always a 'brother to lubricating oil,' and no short circuits can be caused by

The manufacturers make the following suggestions and directions regarding the use of armalac:—

"When it is proposed to paint double-cotton covered armature and field-magnet wires, it is advisable to put them in the stove

oil in machines insulated with armalac. It dries very rapidly, and its method of application is similar to that of shellac or varnish.

"Its cost varies from $\frac{1}{250}$ to $\frac{1}{1000}$ part of the value of the machine it permanently protects."

In another publication the manufacturers of armalac set forth the following definitions and criticisms of impregnating materials based on other principles:—

"French copal or spirit varnishes are composed of fossilised or unfossilised resin acid gums dissolved in spirits to form a rapid-drying varnish more brittle than shellac and less capable of arresting moisture. Resin acids are in precariously weak union.

"Asphaltum, japan, black varnish are various compounds of bitumen in solution in naphtha, turpentine, and carbon bi-sulphide, in which an attempt is made to lessen the natural brittleness of the asphaltum by tempering it with linseed oil, pitch, or rubber. These tempering materials are very short-lived; the compound is quickly reduced to powder by the heat and vibration of the coil, whereby the powdered asphaltum mechanically loses its power to exclude moisture and give insulation resistance.

"Linseed oil.—A vegetable oil, having commercial value because of the rapidity with which it absorbs oxygen. It is very durable for house paint and furniture varnish, but the heat and intense oxidation of a well-ventilated armature quickly convert it into linoxyn, a brittle powder which absorbs moisture. Of all materials tested, linseed oil gives the greatest assistance to the impregnation of cotton covering with copper salts.

"Oil varnishes are composed of fossilised and unfossilised resin acid gums melted in linseed oil, thinned with turpentine and naphtha in the process. This name covers an almost endless number of compounds, varying chiefly in the proportions of oil and gums. They present all the defects of 'spirit varnishes' increased by the defects of linseed oil.

"A number of spirit and oil varnishes have been exploited wherein the makers have attempted to obviate the defect of brittleness by the introduction of slow-drying oils, such as cotton oil, rape oil, corn oil, etc. These show up somewhat better than true linseed oil varnishes in superficial tests, but the severity of actual working conditions shows them to be much more defective.

"Copper Salts.—The action of acid on copper is so widely known that its introduction into coils of copper wire by intelligent men is almost beyond belief, yet shellac-varnish, gums, linseed oil, rubber and pitch, composed almost entirely of acids, are every day daubed and soaked into the copper vitals of high-cost machines.

"A varnish may show magnificent insulation and resistance to moisture and ...t at the outset of its career, but it must be condemned as worthless if its ... are quickly shattered by oxidation and powdered by vibration, or if it ...mbine with copper and impregnate cotton covering with a metallic salt ...l conductivity."

first, so as to dry out the slight amount of moisture that is usually present, and then they can be painted over with, or dipped in, cold armalac.

"Armalac dries quicker than any other compound, but it does not dry brittle. Every particle of liquid leaves the layer of armalac in less than thirty minutes, but the film remains permanently plastic, though not sticky. This plastic quality is not because of the presence of slow-drying oils; they are not permanently plastic, and armalac is. Frequently electricians have unsuccessfully tried to bake armalac hard.

"It will be noticed, probably, when painting, that armalac apparently goes right through the cotton covering and hardly shows on the outside. This is as it should be, since it practically insulates the copper itself, but by giving it another coating you can also fill up the cotton and make it practically a double insulation. It will usually be found in armatures insulated with shellac, that the tape becomes very brittle and tears like paper; this, however, does not occur when armalac is used, as it has no tendency to this disruptive effect.

"Former wound coils are preferably treated by being dipped in armalac, and then suspended either for a short time in a drying stove or for, say, half an hour to one hour in the air, and they can then be bent and driven into place without any scaling off of the insulation.

"This plasticity enables the films of the compound between layers of wire to come and go with the expansion, contraction, and vibration of the windings of a coil without powdering or mechanically losing their initial resistance, and armalac is the only compound known to-day which permanently retains this first requisite of good insulation.

"In several works cotton-covered wires are passed through a bath of armalac, and then are dried mechanically by passing either through a warm tube or through a chamber with several small fans causing a draught, which promptly dries off the petroleum naphtha, and it can then be used at once for various purposes. For ordinary uses armalac may be applied exactly the same as shellac or varnish, but, as before mentioned, it requires far less baking. If armalac should seem too heavy in body for any particular purpose (it is

usually not found so), it may be diluted with benzine, and in thus changing the specific gravity it is advisable to have a hydrometer, so that it may be kept fairly constant to the particular body or specific gravity required.

"Mix nothing with armalac. Dilute (when made necessary by evaporation) only with petroleum naphtha. Have all mechanical parts of coils perfectly clean and dry. Use closely woven cotton cloth instead of rubber tape. Cloth should be put in place, fastened, and then saturated with armalac. Saturate each layer of wire with armalac."

Certain disadvantages attending the use of armalac as applied to armature insulations relate to its tendency to ooze out under the influence of high centrifugal forces and heat.[1] Its insulating quality, while not high, is stated to be exceedingly constant, and it may often be used to advantage on the stationary parts of dynamo-electric machinery. There are various varnishes of the gilsonite and asphaltum orders which, while permanently plastic, are less liable to fly out under the influence of centrifugal forces and heat, and have a higher disruptive strength than armalac. They are, however, not entirely free from vegetable acids, and any corrosive effects would be less readily discovered, owing to their colour.

No one varnish is suitable for all purposes. A varnish with corrosive propensities may be safely used, provided another varnish free from this propensity is first applied next the copper to shield it.[2] A varnish which always remains soft and pliable is exceedingly useful for form-wound armature coils, as flexibility is essential in assembling and especially in repairing such coils. In some cases a varnish need have but moderately high insulating properties, if only it has durability and toughness. In other cases,

[1] "If high melting-point is forthcoming, coils or armatures may be satisfactorily baked. Armatures, however, running at high peripheral speeds, especially turbine armatures, throw off the varnish in which they have been dipped at comparatively low temperatures, as the high centrifugal force assists in this work. This is, of course, a great disadvantage."—*The Electrical Engineer* for September 16, 1904, p. 412, "On Insulation."

[2] "Complaints are heard of the attack of some varnishes on particularly thin wires. For such purposes it may be well to prevent direct touch of the varnish and the metal by an intermediate coating."—Dr Max von Recklinghausen.

the ability to dissipate heat is a recommendation. For some purposes the varnish must dry quickly in the air,[1] and present a hard, smooth surface, to which dust and oils will not readily adhere. In some cases a waterproof varnish is indispensable, and in still other cases the varnish must resist the action of acid fumes or of heat. Where great vibration is present, as in high-speed armatures, copal and asphaltum varnishes are liable to pulverise.[2]

A varnish is supplied under the trade name of "Dielectric Varnish," which is stated to be "a perfectly pure linseed oil gum varnish, for baking only," and that it is "absolutely free from rosin, metallic dryer, and from free acid or other acids, except the combined acids of the linseed oil." The material is stated to have great elasticity after baking, and the very highest dielectric strength and ohmic resistance. It is especially designed for building up skin insulation on the outside of copper coils. This material would appear to be not unlike Sterling Varnish.

The same firm supplies a paraffin varnish under the trade name of "Dielectrol," and describes it as "a black fluid insulating compound for the inside of copper coils, either for application by painting on the coils as they are being wound, or for dipping after

[1] "It will be obvious to anyone acquainted with shop methods the great saving in time and the increased output that can be obtained from a given drying stove, the more 'quick drying' the insulating medium is. With this object in view recourse has been made to shellac, copal, and resin varnishes, using alcohol as a solvent. This would not be objectionable but for the fact that when the spirit (and also the water it carries) has been dried out, the resulting solid is too brittle. This solid under vibration or due to expansion and contraction, as the winding heats up and cools down, is in time reduced to a powder, and is then, of course, useless as an insulator. Should it be a revolving portion of a machine that is insulated with these varnishes, then centrifugal force will assist in the destruction of the insulation. Oil 'varnishes' are not 'quick drying' unless an objectionable amount of 'dryer' is introduced."—*Elec. Engr.*, September 16, 1904, p. 411, "On Insulation."

[2] "From the point of view of elasticity and strength, all mixtures, as distinct from chemical compounds, should be avoided. They are objectionable because of separation through settling. Should this be overcome by frequent stirring it is only temporary, as separation can take place after application. These mixtures are often brittle when thoroughly dry, and this considerably impairs their use. The American asphaltums, or, as they are rechristened here, varnishes, are satisfactory at first as regards elasticity, but in time become brittle."—*Elec. Engr.* for September 16, 1904, p. 412, "On Insulation."

the coils are completed." The material is stated to be "chemically inert, of paraffin origin," and to have a flowing point, sufficiently high to ensure its permanent retention on the coil during all working conditions. It is claimed that it is permanently plastic and *air dries in a few minutes*, but "baking is recommended, as it drives out the moisture from the cotton covering and allows the excess of material to drain off."

In one of their publications the manufacturers of this varnish set forth the argument that a minimum of thickness of insulation between turns is generally required for insulation purposes, if only this insulating distance can be preserved, and its efficiency as a dielectric maintained unimpaired. The problem is thus to keep conducting material permanently out, and this means the exclusion of moisture, "as well as possible decomposition products of irrational insulating varnishes; and to keep the wires apart." "Here a mechanical consideration enters. Double cotton covering is a weak material to bear the handling of the armature winder, and the different forces tending to pull, drag, and throw the wires out of their proper places. It is desirable, therefore, to cement the turns together by a permanently plastic, tough and penetrating material, possessing the other requirements of being chemically inert and moisture-proof."

"Empire" Insulating Varnish is described by its manufacturers as a black oil varnish with extremely high penetrating properties, "taking and drying very rapidly." It is further stated to be "perfectly flexible, to have remarkably high insulating properties," and to be "proof against acids, salt, and moisture," and not to "blister under heat."

The following instructions are given for its use:—

"First, dry the coils by baking at about 100° Cent., taking care that all moisture is completely expelled. Dip the coils, while still hot, in the varnish until they are thoroughly saturated, then replace in the baking oven for half-an-hour at about 100° Cent., making provision for the surplus varnish to drain out. When all dripping ceases, allow the coils to cool. When cold, a coat of varnish may be given with a brush, when the finished coils will have a glossy black appearance, as if enamelled."

Most of these firms' best quality varnishes range in price from four to six shillings per gallon.

"Berrite"[1] is an impregnating gum. It is brittle, but has high disruptive strength, a sample ·079 cm. thick being punctured by 15,700 volts; runs freely at rather a low temperature, but its insulating qualities are unaffected by very great heat; is good for impregnating paper and cloth, but papers so treated, though rendered tough, require great care to prevent cracking. Symons' results for the disruptive strength of "Berrite" are given in the curves of fig. 84A.

It has been pointed out in various quarters that linseed oil varnishes should be the more avoided the more the apparatus approaches the "ventilated" type. However this may be, the argument has been put as follows:—

"Continued high temperature tends to produce brittleness, due to oxidation; it is for this reason that the author is of the opinion that it is inadvisable to use paper or linen impregnated with linseed oil for the insulation of armatures of dynamo-electric machinery: linseed oil has a great affinity for oxygen, and in modern design good ventilation is given the armatures of machines, and these, when warm, will help to produce oxidation of the impregnating linseed oil, and thus produce brittleness; this question of the insulation of the armatures of dynamo-electric machines is one of immense importance, their successful running depending upon their insulation, and it is a very severe treatment of any dielectric, as the temperature is constantly changing, sometimes very high temperatures being attained by continued running on overload." (Symons, "Insulation and Insulators.")

Linseed oil has the property of swelling when drying,[2] and when heated to the boiling point, its penetrating properties cause it to

[1] "Insulation and Insulators," H. D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.)

[2] This has been pointed out by Fessenden (see p. 144). Symons, in referring to this property, states:—

"Linseed oil is an extremely good oil for impregnating purposes, and has the remarkable property of expanding on drying, but, as before stated, it is not suitable for armature insulation."—"Insulation and Insulators," H. D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.)

fill the pores of woods and of fibrous materials in general. Moisture is thus excluded, and the insulating properties of the impregnated material are greatly enhanced. A little paraffin wax can well be added to the linseed oil when employed for impregnating purposes.

It is convenient to have a large tank heated with steam pipes, maintaining the double-boiled linseed oil constantly near the boiling point. Prior to dipping in the linseed oil, the materials to be impregnated should be dried out in a vacuum oven. They should then be placed in the oil tank for twenty-four hours, and should finally be again baked at not over 70° Cent. in an oven from which the air is not excluded. This enables the linseed oil to harden through oxidisation.

Carbon bisulphide, benzol, naphtha, and turpentine figure largely as solvents for impregnating materials, and are each in themselves good insulators.

The so-called Japan varnishes vary greatly in their composition and disruptive strength.

Varnishes of collodion and celluloid compositions may be employed in providing copper wires with a tough, durable, and pliable insulating skin, which will not readily crack. Wires so treated are gradually coming into use in certain cases where the space factor would otherwise be very low, but the extensive use of such methods must be preceded by a great deal of experimental development.

The results of some comparative tests on the use of two sorts of varnishes on several different materials are given in Table XXX. Each result is the average of tests on several samples. The results show in an interesting way *that one varnish may give the best results with one material, and another varnish with some other material.*

Fessenden[1] has made a number of valuable suggestions on the subject of impregnating varnishes, based upon his extensive experience:—

"In cases where cloth is to be treated we have a very different question. There are two ways of using cloth, first as a backing

[1] "Insulation and Conduction," *Proc. Am. Inst. Elec. Engrs.*, vol. xv., 1898, pp. 148–150.

merely, by coating it on the surface with some substance which is supported by it, as plaster on lathing. Many substances work well in this situation, but the fact that little tubes of cellulose are very apt to stick up through the coating, as was pointed out to me by Mr F. R. Upton many years ago, and that if moisture

TABLE XXX.—COMPARATIVE TESTS OF THE DISRUPTIVE STRENGTH OF MATERIALS IMPREGNATED WITH VARIOUS VARNISHES.

Varnish.	Material.	Thickness per Layer before Dipping (mm.).	Thickness per Layer after Dipping (mm.).	Volts per 0·01 mm. of Final Thickness.	
				One Layer.	Two Layers.
"Sticker"	Red rope paper . . .	0·105	0·18	360	327
	Grey rope paper . .	0·20	0·32	155	157
	Red rope paper . . .	0·23	0·32	113	121
	Horn fibre	0·56	0·66	133	129
	Bleached cotton cloth .	0·17	0·44	103	96
	6 oz. cotton drill . .	0·52	0·67	38	37
"Voltalac"	Red rope paper . . .	0·105	0·16	231	277
	Grey rope paper . .	0·20	0·26	190	139
	Red rope paper . . .	0·23	0·30	151	192
	Horn fibre	0·56	0·74	117	135
	Bleached cotton cloth .	0·17	0·28	186	150
	6 oz. cotton drill . .	0·56	0·60	29	20

gets in at the edge it spreads all over, renders it not the best kind of insulation. Rubber is sometimes applied in this way to cotton tape, but though at first of very high resistance and insulation, it rapidly deteriorates. In general it may be said that where a permanent result is desired, rubber should never be used unless kept in the dark and out of contact with air. If these precautions be neglected the life is very short. The other method is to saturate the whole cloth with some substance which will penetrate every crevice, but when this impregnating substance has solidified, it must continue to fill these crevices and capillary tubes. For this reason no substance which is dissolved in anything else can be used. If, for instance, we try a varnish dissolved in alcohol, it will be found that the strength of the solution in the capillary tubes is much smaller than outside, for the same reason that sea water filtered through sand becomes fresh (J. J. Thompson, *App. of Dyn. to Phys. and Chem.*, p. 190). Consequently, on drying,

these capillary spaces are not filled up, and let water : Therefore, unless we adopt the first method and plaster t insulator on thickly and deep enough, so that it does not matt whether the support insulates or not, we must use melted soli or drying oils. Unfortunately, but few solids which melt a elastic, since this elasticity is obtained by a structure which destroyed by melting, and those solids which melt into th liquids and remain flexible when solid do not preserve th property, except within narrow limits of temperature, as can l easily tested by holding under a cold-water tap, and striking tl specimen sharply. Soft paraffin can be used in some cases if tl cellulose be well dried and thoroughly saturated. The asphal cannot, as a rule, be used, as they never get sufficiently fluid c melting. There is, however, one notable exception—uintaite, (as it is commercially called, gilsonite. This substance I foun many years ago, had the peculiar property that when melted would, like paraffin or oil, pass into the pores of cellulose or clot] Having a very high melting point, nearly 300° if I remember, an mixing perfectly with paraffin in all proportions, it gives mixture which are admirably adapted for induction coil work, as thes compounds can be made to have high melting points and t penetrate a coil thoroughly. I also, some years later, in 189: used this material in combination with linseed oil for transformer: the process at first proposed being boiling in vacuum, but it wa found that even without this, saturation was complete. I under stand that this method is still used, though modified in form, b: the company for which I first devised it. Of the drying oils, wit] the exception of some foreign oils, as Chinese wood oil, and a] African oil whose name I cannot recollect or ascertain, linseed oi and the drying nut oils are the best. Linseed oil has the remark able property of expanding on drying. This enables it to fill u] all pores. Its durability is evinced by the good condition of ol(oil paintings. The varnishes crack and go, but the oil remains Its insulation is not injured, up to very high temperatures, a which shellac, rubber, etc. would be worthless. This materia: was used a great deal by the Edison Company in its early days but it often broke down. The trouble was traced to the lead drier, and after many experiments Mr Marshall, who had

charge of this work, finally settled upon the use of pure raw oil. This gave excellent results and was long used, but took some time to dry; and the writer finally, after many tests, found that borate of manganese drier got rid of the trouble, while, as is well known, it gives a very quick-drying varnish. This was used by the United States Company in Newark on their machines, with the result that in 1890, after use for a year, the foreman reported only two armatures so treated as returned for repair (they were injured by lightning), and no fields. This material was also used by the Stanley Company for transformers. Another advantage of this borated oil is, that it always retains a slight stickiness, and so gives a good joint when wrapping around wires, etc. Many substances so used are not sticky, and let moisture in through the joints. Where a smooth surface is required, it is readily obtained by dusting on a little talc, a method first suggested, I believe, by Mr Edison. It can also be given a coat of japan on the outside. Varnish gums should never be used with linseed oil, as they are brittle, and the dried oil is only just flexible enough. Consequently when the oil has dried, the resultant varnish is always very brittle. A temporary elasticity is given at first by the fact that when the solvent has dried off the oil is still fluid and undried, and as the varnish gum keeps the air from getting at it rapidly, it sometimes remains flexible for a year. Such mixtures also crack when cold.

"Sample C is a specimen of borated-oil saturated cloth, which is now between eight and nine years old. It will be noted that it is still fresh and flexible, and a recent dielectric strength test showed up very high—15,000 volts, if I recollect. The pure raw oil is boiled at about 200° with $\frac{1}{2}$ per cent. of borate of manganese for several hours till it begins to be thick.

"Non-inflammable materials can be made, as I have pointed out elsewhere, by taking out the hydrogen atoms of hydrocarbons and substituting chlorine. Even paraffin can be thus treated if kept warm, and first turns to a fluid and then to solid. At one time it seemed as if this process might be valuable, but the use of enclosed conduits has done away with the greatest source of danger from fire.

"I will conclude by describing a couple of devices which I have

found useful in preventing insulation from being spoiled. Soldering acid, as commonly used, is a solution of chloride of zinc. If this falls on cellulose it turns it to a paste. It never evaporates, and always takes up moisture from the air, and will gradually eat its way through quite a thickness of insulation. Whether it is acid or neutral makes no difference so far as its action on the insulation is concerned, though the neutral solution does not corrode the wire. Rosin has the disadvantage that it is not a fluid, and is clumsy to handle. I have found that by shaking up powdered rosin in very strong ammonia an ammonia soap is produced, which works well in most cases. The ammonia dissolves copper oxide and evaporates afterwards, leaving the powdered rosin, which is an insulator."

Holitscher[1] recommends testing varnishes as follows:—

"They should be applied to linen or paper by means of a brush, painting them over in two directions at right angles to one another, or else the linen should be dipped in the material, the top and bottom of the piece of linen being exchanged at each successive dipping in order to ensure as even a coating as practicable. It is important to use the same thickness and quality of linen in all tests. Batiste linen is recommended as a good standard. The sample is then dried, generally at the temperature recommended by the manufacturer, until it is no longer 'sticky.' The disruptive strength of these samples is then tested, cold and warm, flat and after creasing, and the average and minimum values for several samples are recorded. The samples are also tested as to freedom from acid."[2]

[1] *Elek. Zeit.*, February 27, 1902, p. 170.

[2] "The paint or varnish should render the material impervious to moisture, unaffected by oils, acids, and salt water. It is, of course, well known that water is an undesirable attendant of insulation, and, therefore, there is no need to labour this point beyond mentioning the specially adverse conditions to which some outside work is subjected, as, for instance, traction motors of all descriptions, motors for small tools in shipyards, etc. Insulation should certainly not wash off within a reasonable time. Regarding oils, many machines are subjected to trouble from this cause; motors from faulty bearings, etc., and generators from this cause and, where placed between ngine standards, from splashing of oil from the engine. Acids are detrimental insulation, and more than one machine has had to be rewound owing to ɜing subjected to the acid fumes from battery-rooms. Salt water has been

In an article in *The Electrical Engineer* for September 16, 1904 (p. 411), entitled "On Insulation," the following series of tests is suggested for paints and varnishes:—

1. *Quick Drying.*—This is merely a matter for trial, and can be done either in the open air or in a drying stove, as desired.

2. *Elastic Strength.*—This may be tested by coating a piece of presspahn, tin, or copper (metal for preference), and when dry bending backwards and forwards. An electrical test can also be made after the bending, to see if this has affected the insulating material.

3. *High Melting-Point.*—First dry off the liquid components and then heat the residue, and see at what temperature it melts. If the drying was done in a thin layer, it would also be possible to note when it commenced to char.

4. *Affecting Copper.*—Copper strips may be coated and examined after an interval (which is practically working conditions), but a quicker way is to put copper filings into a quantity of the varnish. They will readily show if the varnish will in any way affect the copper.

5. *Waterproof, etc.*—The varnish or paint could be tested on some plant about the works, where there is generally some motor or other, running under adverse circumstances as regards oil, etc. A test might be made of a piece of metal left exposed to the elements for some considerable time.

added by engineers in cases of exposed stations near the coast, especially where the voltage generated is high, though in the case of low voltage it would only be a question of time if the insulation was not impervious to salt water."—"On Insulation," *The Elec. Eng.*, September 16, 1904, p. 412.

CHAPTER IX

HEAT-DISSIPATING IMPREGNATING MATERIALS

A COMPARATIVELY recent innovation in insulating methods relates to the employment of impregnating materials which, while scarcely, if at all, inferior in insulating properties, are of such composition as to facilitate the egress of heat from the interior of coils.

Electro-enamel.—The alleged original and novel features of this varnish, which was the first of its class to be placed on the market, call for a brief description, as it introduces a new factor in insulating methods. It is claimed to be a heat-conducting, acid and moisture proof varnish, with good cementing qualities—a combination which is frequently required.

Electro-enamel was originally produced by a Continental firm as an acid-resisting enamel for coating battery cells and accumulator boxes, and also as a rust preventative on metals, and for moisture-proofing walls, etc. Its usefulness as a heat dissipator was, in the first instance, only accidentally observed. Two small transformers had been wound up, one with and the other without impregnating the cotton coverings on the wires with electro-enamel. These transformers were run with a high overload, and on subsequently stripping them, the one wound without electro-enamel was found to have its cotton coverings thoroughly charred, while the other was in excellent condition. This suggested the idea that if moderately good heat conductivity could be obtained without undue sacrifice of insulating quality it would be a valuable feature, and the varnish has since been developed with this end in view. Low insulating quality was at first a bar to its progress, but after it had been improved in this respect the material was employed in electrical work for moisture-proofing and toughening trans-

former coil insulations. Coils which had given much trouble on account of the gradual deterioration of the insulation due to long and excessive heating, are stated to have been found to be not only greatly improved in durability, but to run decidedly cooler.

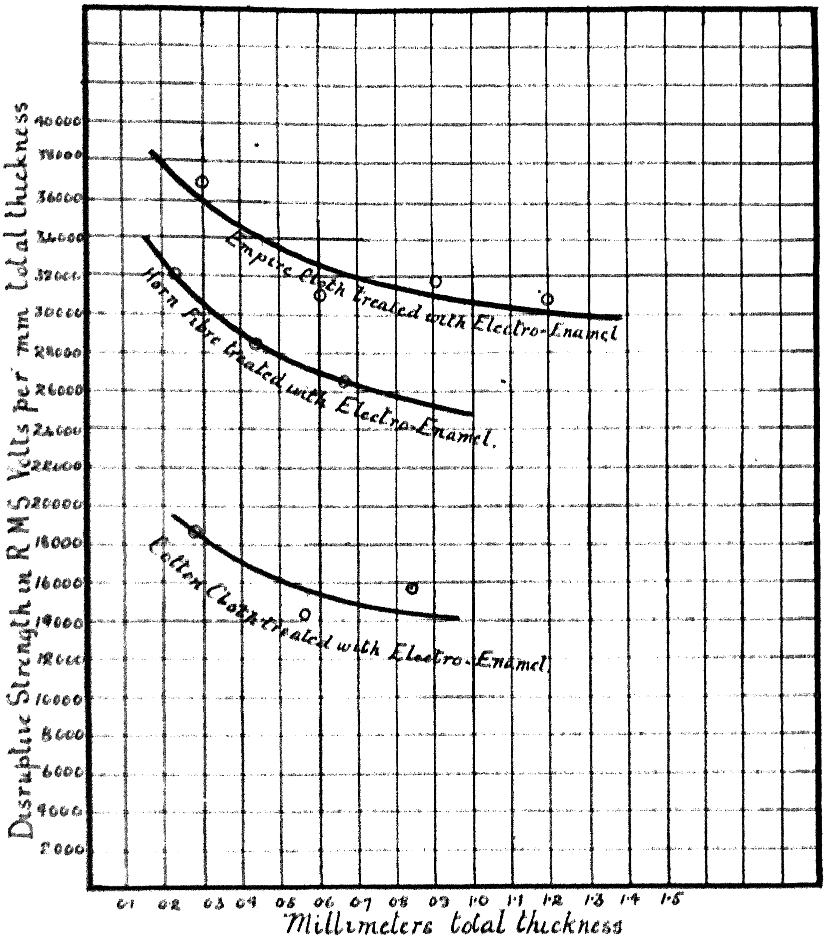


FIG. 66.—Curves of the Disruptive Strength of Materials impregnated with "Electro-Enamel."

It is reported that a rotary converter, which had twice been returned from an accumulator factory in a corroded condition, and with the slot insulation over the ventilating duct thoroughly rotted by acid vapours drawn in by the revolving armature, was treated with electro-enamel with highly satisfactory results. The

use of this material has now been extended over a wide range of work. The cementing property has been taken advantage of in treating sheet asbestos rolled into tubes, and also for dispensing largely with retaining bands, and core shells for coils and bobbins. A comparative test made on a 5 h.p. 4-pole motor, in which two of the four spools with "skeletonised" insulations were treated with one of these heat-dissipating varnishes, is stated to have resulted in showing a temperature difference of 30 per cent. between the two types of spools; and further tests made with this varnish are said to have shown that a current that would thoroughly char the untreated cotton coverings on the wire, but slightly discoloured the varnish-treated insulation, and left its insulating qualities intact.

The results of tests of the disruptive strength of some materials treated with electro-enamel are given in fig. 66.

The manufacturers of electro-enamel give the following directions for use:—Run the wires through a bath of electro-enamel, and wind in a moist state directly upon the winding form. By this method it will be found that a like number of ampere-turns may be got into the same winding space, as with untreated wires, and with the added advantage that the coil, when dried (in an oven), solidifies into a permanently hard and compact mass, rendering taping bands unnecessary.

Armalac Putty.—This is sometimes used to fill the air spaces in field coils, and is made by stirring common whiting into armalac. It is claimed that the use of armalac putty facilitates the dissipation of heat from coils in which it is used.

At least one other varnish manufacturer has now brought out an insulating varnish for which similar heat-dissipating properties are claimed.

CHAPTER X

OIL FOR INSULATING

OIL has now become an established commercial insulating material. So far as relates to dynamo-electric machinery, its use is chiefly in stationary transformers, but in the closely allied apparatus for switchboards and controllers it is also extensively employed, and a knowledge of its insulating properties is essential.

Steinmetz' early investigations upon the insulating properties of various kinds of oil gave the results set forth in Table XXXI.

TABLE XXXI.—STEINMETZ' 1892 TESTS ON OILS.

Material.	Disruptive Strength in maximum Volts per mm.	Remarks.
Melted Paraffin	8100	65° Cent.
Boiled Linseed Oil	8000	21° Cent.
Turpentine Oil	6400	
Crude Lubricating Oil (mineral oil) .	1600	Very impure.
The results relate to thicknesses of 0·05 mm.		

For reference and comparison, it may be said that Steinmetz on the same occasion obtained 1670 volts (maximum) as the disruptive strength of air per millimetre thickness at a thickness of 0·05 mm. Thus his best results for oil indicate a disruptive strength of some five times that of air.

In a paper entitled "Oil as an Insulator" (*Proc. Inst. Elec. Engrs.*, vol. xxi., 1892, p. 244), Hughes investigated various oils, employing a Wimshurst machine, and comparing the relative spark lengths in air and in oil. He directed his attention especially to hydrocarbon oils, such as petroleum and rosin oil. He found great variations in the quality of rosin oil: its insulating quality ranged from "worst castor oil up to a superior degree of gutta-percha." He also found this true of most oils, and states that before using any oil its quality as an insulator should be thoroughly ascertained by electrical tests. With regard to their relative suitability, Hughes states: "In selecting oil of high insulating quality, we must also have regard to the purpose for which it is to be used. Thus, as a self-restoring medium having very quick action, for condensers, transformers, or coils so closely wound as to be difficult for a thick oil to penetrate, a thin rosin oil, such as rosin spirit, might be best; but for cables and underground wires, I found thick, pure rosin oil best, because it was not only superior as an insulator, but it would not escape too rapidly at any large puncture."

Hughes found by immersing samples of gutta-percha and india-rubber in separate vases of different oils, and weighing them before and after prolonged immersion, that some oils were injurious to gutta-percha, and that almost all, with the exception of castor oil, were more or less destructive to india-rubber. Pure rosin oil was found to give the highest insulation of all, and a spark that would pierce a given thickness of gutta-percha would utterly fail to pierce the same thickness of rosin oil. Rosin oil was found to have a preservative effect upon gutta-percha, for the sheets after immersion were found to have become slightly increased in weight, showing that the oil had penetrated into the pores of the gutta-percha; it was also found to be stiffer and tougher than before the immersion.

Rosin oil which is already thick and viscid can be rendered more so, when desired, by the addition of solid rosin dissolved in it, or by the addition of palm oil residue, which has the remarkable property of thickening rosin oil.

Hughes found that a spark which would pierce 100 mm. of air would not pierce 1·4 millimetres of rosin oil, the rosin oil

thus appearing to have over 70 times higher insulation than air. Professor Hughes was wrong in taking the dielectric strength proportional to the relative spark lengths, for we know that—at any rate, for air—a doubled voltage will pierce a more than doubled thickness of air (see figs. 12, 20A, 20B, 20C, 36, 38, and 39).

In the discussion on Hughes' paper, Mr A. A. Campbell Swinton gave the results which he had obtained with an induction coil in comparing rosin oil with air. These results are reproduced in Table XXXII., and show at the maximum but 10 times greater disruptive strength for rosin oil, as against 70 times found by Professor Hughes. In most of Swinton's tests the oil showed some four times the disruptive strength of air.

TABLE XXXII.—SWINTON'S TESTS ON RELATIVE SPARK LENGTHS IN AIR AND IN ROSIN OIL.

Spark in Air (mm.).	Spark in Rosin Oil (mm.).	Ratio.
25·4	2·54	0·10
28·6	5·08	0·18
38·0	7·61	0·20
38·0	10·2	0·27
44·4	12·7	0·29
69·7	25·4	0·36
130	38·1	0·29
200	50·8	0·25

With ordinary commercial paraffin, Swinton found half the insulation strength of rosin oil. Fleming pointed out that it is preferable to subject materials to a preliminary immersion in thin oils, as such stiff oils as resinous oils do not penetrate readily. Afterwards the coil may be immersed in a thick oil. H. Cuthbert Hall spoke of the extremely large temperature coefficient of oils, particularly of resin oil. The variation in the specific resistance may amount to as much as 10 per cent. per degree Centigrade at 17° Cent., and at higher temperatures the rate of variation rapidly becomes greater. Before use the oil should be very slowly raised to a high temperature, in order to drive off moisture and the light volatile oils which are always present in the resin oil of commerce, and are inferior to resin oil in insulating properties. The objection to the use of thick oil may be overcome by heating it to a high temperature, and impregnating the material or the

coil with it while still at this temperature. This is better than using oils of greater fluidity, as the latter are not such good insulators. H. Cuthbert Hall has found the best mixture, both as regards specific resistance and disruptive strength, to be three parts of solid resin and one part of first-run oil. Resin is

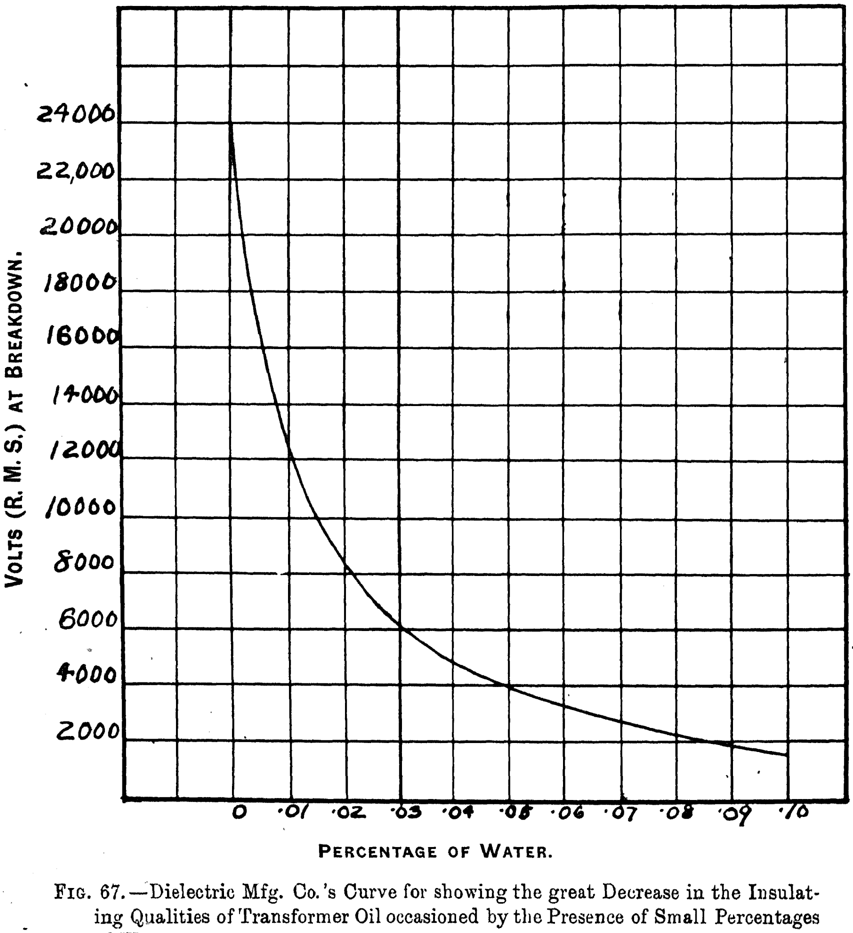


FIG. 67.—Dielectric Mfg. Co.'s Curve for showing the great Decrease in the Insulating Qualities of Transformer Oil occasioned by the Presence of Small Percentages of Water.

nowadays largely adulterated, and it is very difficult to get oil of such insulating quality as was obtainable in former times.

A mineral oil is generally employed in transformers. "Transil" oil is a brand which has been widely employed with success. It has been found to lead to much less trouble from carbonaceous

deposits than is the case with vegetable oils. In fig. 67 is given a curve taken from a publication of the Dielectric Manufacturing Co., showing the serious effect of small percentages of water upon the disruptive strength of mineral oils. The addition of $\frac{1}{10}$th of 1 per cent. of water reduced the disruptive strength to $\frac{1}{13}$th of the value for dry oil. Skinner's tests on the effect upon the disruptive strength of oil of the percentage of contained water are given in the curve of fig. 68. It is evident that the

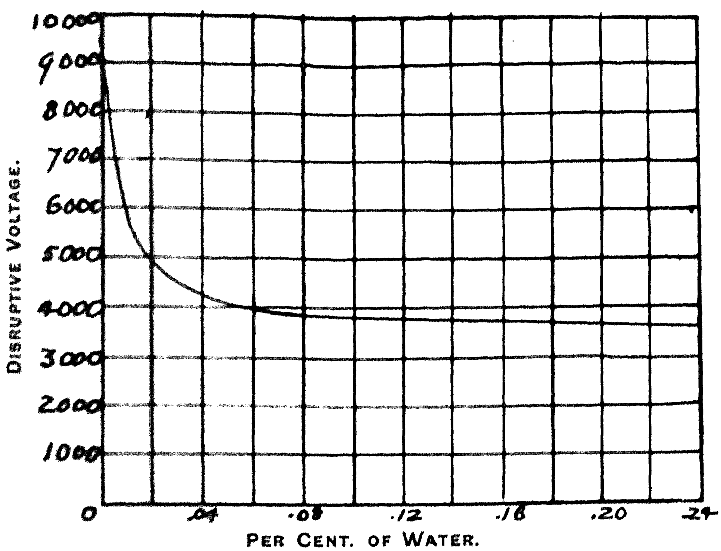


FIG. 68.—Skinner's Curve for showing the Relation between the Disruptive Voltage of Transformer Oil and the Percentage of Contained Water.

Terminals, ½″ balls. Frequency, 113 cycles.
Gap, 0·075″. Wave form, sine.

deteriorating effect of moisture on the insulating quality of an oil is very marked. The effects of oil on mica and on commutators have been discussed on pp. 95 to 103 and on p. 126.

The effect of temperature on the resistance of oils is well illustrated by some of the curves of fig. 70, on p. 160 of the next chapter.

A paper by Mr C. E. Skinner, read before the National Electric Light Association, Boston, Mass. (1904),[1] deals very fully with this subject. Mr Skinner refers to the earlier periods of the use of oil

[1] See also an article entitled "Transformer Oil," by C. E. Skinner, on p. 227 of *The Electric Club Journal* for May 1904 (vol. i. No. 4).

for insulating transformers. Resin oil, linseed oil, and cotton-seed oil were, he states, then used, but it was soon demonstrated that mineral oils obtained from petroleum products were not only cheaper but more satisfactory, and they were ultimately almost universally adopted for use in transformers and switches. Mineral, vegetable, and animal oils, when pure, are all, in Mr Skinner's experience, very good insulators. While he has found a wide difference in the insulating qualities of various mineral oils, this difference has been more an index to the purity of the oil than to any inherent difference due to variations in the chemical composition of the oil itself. The impurities found in oil comprise acid, alkali, water, and other foreign matter.

Mr Skinner states that mineral oils begin to evaporate slightly at a temperature somewhat below their flashing point, and the evaporation is quite rapid at the flashing point and above.

Mr Skinner's article contains the following specification for a transformer oil:—

(1) The oil should be a pure mineral oil obtained by fractional distillation of petroleum, unmixed with any other substances, and without subsequent chemical treatment.

(2) The flash test of the oil should not be less than 180° C. (365° F.), and the burning test should not be less than 200° C. (392° F.).

(3) The oil must not contain moisture, acid, alkali, or sulphur compounds.

(4) The oil should not show an evaporation of more than 0·2 per cent. when heated at 100° C. for eight hours.

(5) It is desirable that the oil be as fluid as possible, and that the colour be as light as can be obtained in an untreated oil.

He states that "an oil which meets the foregoing specifications should prove a first-class insulator." "In addition to the specification, the user should have the assurance that the oil is carefully made; that all containing vessels are clean and free from moisture; and that systematic tests are made on the finished material to see that it fulfils the conditions specified. He should also take the necessary precautions to see that no moisture is allowed to get into the oil after it is received by him. When oil is stored in barrels, the barrels should be kept under cover, and water should not be

allowed to stand on the heads, as it will often find its way through into the oil. Metal cans and drums are far more satisfactory for shipping and storing oil than barrels, for the reason that they can be made practically oil and water tight, and there is therefore much less danger of the oil becoming wet during shipment and storage. The use of metal vessels also eliminates the glue which it is necessary to use in wooden barrels to make them tight. The transformer and transformer tanks should be thoroughly dried before the oil is put in, and every possible precaution should be taken to prevent water entering the transformer case after installation. In water-cooled transformers the cooling coils should be perfectly tight, and the end of the cooling coils where the water enters should be lagged so as to prevent condensation of moisture, due to this part of the coil being colder than the surrounding air."

"When a good oil has been obtained from the manufacturer and the necessary precautions have been taken to ensure that it is kept clean and free from moisture, it may be relied upon as one of the most satisfactory insulating mediums known."

For impregnating wood and fibrous materials generally, linseed oil is most suitable on account of its penetrating qualities, and of the fact that it expands on drying, thus filling up the pores and preventing the subsequent entrance of moisture. All materials which are to be impregnated with linseed oil should first be dried in a vacuum oven, and immediately plunged into a bath of hot linseed oil, left there for twenty-four hours, and then dried in an ordinary oven, but at a temperature not exceeding 70° C.

Oil for Oil Switches.—Skinner states that the requirements of oil for use in oil switches are very similar to the requirements of oil for transformers. Oil having a very low "cold test" may be desirable for use in switches which are intended for outdoor work. A fairly viscous oil has given the best results in oil switches, and Skinner suggests that this may be on account of the fact that it is not so easily displaced by the arc as would be the case with a lighter oil. Skinner states that in other respects "the requirements throughout may be stated as being exactly the same for both transformer and switch work, and it has been found possible to manufacture an oil which is entirely suitable for both purposes."

CHAPTER XI

THE TESTING OF LIQUID AND VISCOUS INSULATING MA

HUMANN has described (*E.T.Z.*, December 31, 1903, p useful method for determining the insulation resistance insulating materials and of viscous insulating materia especially useful in the comparison of oils for use in hig switches and transformers. In the choice of such oils, "i a high disruptive strength essential, but a high insulation as measured in megohms, is also desirable."

At ordinary temperatures, the specific resistance of such is so high as to render its determination exceedingly However, it rapidly decreases with increasing tempera this phenomenon is taken advantage of in the meth consideration, which is employed in the laboratory of th Felten & Guilleaume.

The material to be investigated is first heated until all has been eliminated. It is then poured into the vess apparatus illustrated in fig. 69, and its insulation resis various temperatures is measured. In fig. 69, K de containing vessel. H is a piece of hard rubber, to which testing electrodes A A are secured in such a manner and a distance apart as to avoid leakage. The electrodes A A in the material to be tested, are set at a suitable distan mm. apart. The temperature is observed by a thermome bulb lies in the liquid and against one of the electrodes.

The measurements are commenced at about 120° Cen case of very high resistance materials. For other ma lower temperature suffices. The temperature is gradu creased, and measurements are made from time to tim

temperature is reached corresponding to so high an insulation resistance as to preclude correct determinations. If the electrodes are 0·1 cm. apart, and have a cross section of 25 sq. cm., then the specific resistance in megohms per cubic centimetre is obtained from the observed insulation resistance in megohms by multiplying by 250.

In the curves of fig. 70 are plotted the results obtained on a number of oils and other insulating materials.

Although it is not always possible from the curves to draw precise conclusions as to the insulation resistance at 20° Cent., the curves

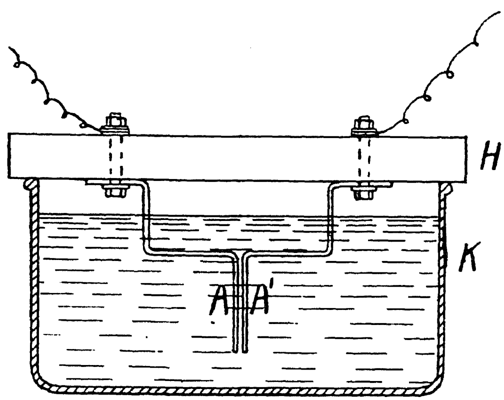


FIG. 69.—Humann's Apparatus for testing the Ohmic Insulation Resistance of Liquid and Viscous Insulating Materials.

nevertheless afford data from which the relative insulating quality can be determined.

Skinner's apparatus for testing the disruptive strength of oil by means of an immersed spark gap is illustrated in fig. 71. The apparatus comprises a 200 cubic centimetre graduated glass cylinder of 35 millimetres inside diameter. A hole is drilled through the bottom of this testing cup and the lower terminal is inserted through this hole. Mr Skinner's description, taken from a paper read at the 1904 Convention of the National Electric Light Association, continues as follows:—

"The testing terminals consist of $\frac{1}{2}$-inch diameter brass balls fastened to $\frac{3}{16}$-inch rods. The upper rod passes through a clamp which is connected to a micrometer screw, actuated by a milled head. The lower terminal should fit in a socket, so that it may be

readily removed for cleaning. The bottom of the cup is made oil-tight by the use of gaskets where the lower rod passes through the cup. An extension of the lower rod comes in contact with a spring set in the base of the stand, to which the line terminal is connected by means of a convenient binding post. Stops are provided so that the oil vessel may always be placed in the same position.

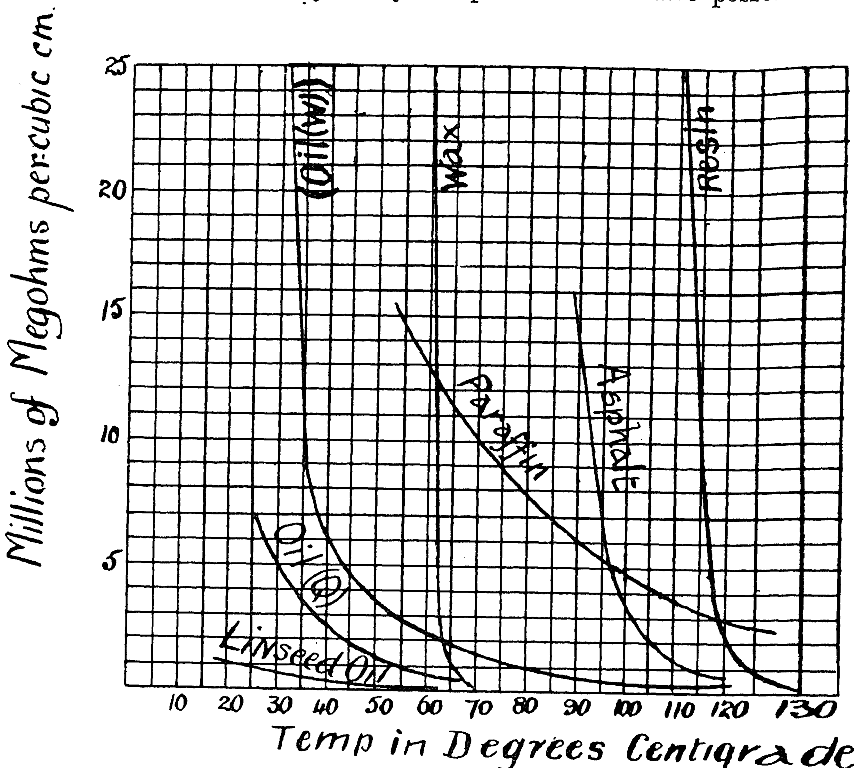


FIG. 70.—Humann's Curves for the Ohmic Insulation Resistance of Various Oils and other Liquid and Viscous Insulating Materials.

The upper rod may slide up and down easily when the clamping screw is free, or may be engaged with the micrometer screw at any point for adjusting the gap. All parts are therefore readily accessible for cleaning, and the zero point of the gap may be quickly adjusted for each test by allowing the upper rod to slide down so that the terminals are in contact, and then clamping to the micrometer screw. The apparatus is always filled to the 200 c.c. mark (requiring a little less than 200 c.c. of oil for each

test). The gap is adjusted to any convenient amount, usually 0·15 inch (3·8 mm.), and the e.m.f. is raised gradually until break-down occurs. After trying numerous forms of testing apparatus for this purpose, this method has been adopted as the most convenient, and

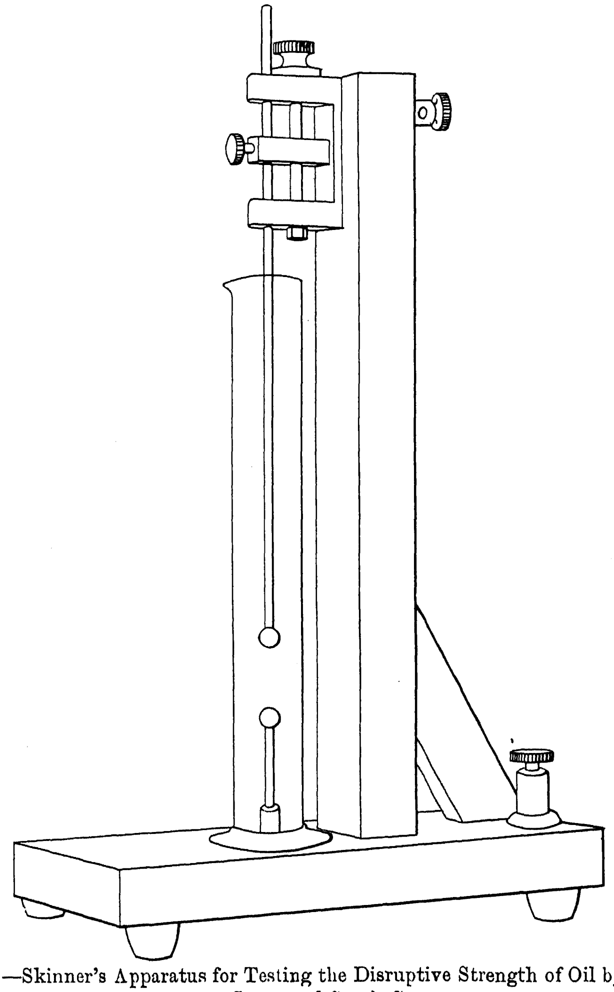


FIG. 71.—Skinner's Apparatus for Testing the Disruptive Strength of Oil by means of an Immersed Spark Gap.

it has the advantage of requiring a comparatively small amount of oil for each test."

Mr Skinner has found that a large number of precautions are necessary in such tests if any approach to consistent values is to be obtained:—

"The spark gap terminals should always be of the same shape and nicely polished, especially if the gap is quite small. Slight roughness or points on the testing terminals will change the apparent dielectric strength of the oil.

"The gap should always be at the same depth in the oil, consequently a variation of the pressure will cause a variation in the tests. The apparent insulating strength increases with the pressure.

"The testing voltage should always be applied in the same manner. It is preferable to fix the gap, and apply an increasing voltage until break-down occurs; or a constant voltage may be applied, and the gap gradually shortened until the distance becomes such that rupture occurs. In the former method the voltage may be very gradually increased, as may be done by controlling the field of the generator, or it may be applied in steps, either with or without opening the circuits between steps; but for comparative purposes one method only should be used.

"The time of application of the voltage should be as nearly as possible the same, especially the time consumed after the voltage reaches, say, 50 per cent. of the dielectric strength. A longer time will give lower results, especially if the oil contains impurities which may line up between the testing terminals.

"It is a good plan to make more than one test on each sample of oil, as the test value frequently increases with the first few tests, especially if the oil is well shaken after each test, so as to thoroughly mix with the oil the carbon formed by the arc, and not allow it to concentrate between the testing terminals. When so shaken, it must be allowed to stand until free from air bubbles before another test is made. This increase in dielectric strength seems to be due to the drying effect, or to the burning out of impurities in the oil. The best oils do not usually show much increase with repeated tests. When the oil becomes very black and dirty from repeated tests, the dielectric strength drops rapidly.

"The amount of oil used for each test should be the same in every case, especially if more than one break is made in each sample. It is obvious that the carbon formed by the burning of the oil will be disseminated through the oil, and that the results will depend in some measure upon the amount per cubic inch of oil. It follows from the above that if more than one test is to be

made on a given sample, the amount of energy expended by the arc formed, due to the rupture of the oil, should be the same as nearly as possible for each break. It is best to limit this to a comparatively small amount by a fuse or circuit breaker in the primary of the testing transformer, arranged to open the circuit on a comparatively small current. By using small currents the work of keeping the terminals clean is much facilitated.

"The frequency of the e.m.f. wave form of the testing circuit should be kept the same in the successive tests. It was pointed out some years ago by Professor Elihu Thomson that oil is not as good an insulator for low as for high frequencies. There is, however, little variation for commercial frequencies. It is well known that a pointed or saw-tooth e.m.f. wave will break down insulation of all kinds more readily than a flat, smooth wave of the same square root of mean square e.m.f. *The use of a resistance for varying the testing voltage is therefore very objectionable.*

"All vessels and apparatus used must be kept perfectly clean. A single fibre in the oil may reduce the dielectric strength greatly if it happens to 'line up' between the terminals. A small amount of moisture is particularly objectionable, on account of the very great reduction which it may make in the insulating value of the oil.

"It is best to allow the oil to stand a short time after pouring it into the testing vessel, as the bubbles of air which are carried with the oil in pouring in, or due to the oil being agitated, will lower the apparent dielectric strength."

Flash and fire tests should also be made upon the oil. Mr Skinner defines the flash temperature as that "temperature to which the oil must be heated in order to give off gases at such a rate as to form an explosive mixture with the surrounding air." By "fire test" he denotes the "temperature to which the oil must be heated, so that the oil itself will take fire and continue burning when a flame is applied to its surface."

In determining these temperatures, the oil is heated gradually and a test flame is applied at intervals, and the two temperatures are determined at which there occurs respectively a slight flash on the surface and an actual ignition, followed by continued burning.

The apparatus on the market for making flash and fire tests may

be divided into two classes, which Mr Skinner defines as the "open cup" and the "closed cup" methods.

"For oils having a flashing point as high as ordinary transformer oil, the open cup method is preferable. The results reached by any method will depend largely on the taking of various precautions which have been summarised by Gill in his *Handbook of Oil Analysis* as follows:—

"'1. *The Rate of Heating.*—The faster the oil is heated the lower will be the flash point, as more vapour is driven out.

"'2. *Size and Depth of Cup.*—From a large and shallow cup the liquid evaporates faster; hence the lower will be the flash point. The most constant results are obtained from a deep cup about half filled.

"'3. *Quantity of Oil.*—The larger the amount of oil the more vapour will be driven out; hence the lower will be the flash point.

"'4. *Distance of Testing Flame.*—The nearer, or what amounts to the same thing, the larger the testing flame, the lower will be the flash point. A large flame may produce local superheating.

"'5. *Point of Application of Testing Flame.*—The flame should be applied at the edge, as the mixture of air and vapour is more complete. This is best effected by drawing the flame diametrically across the top of the cup. Dr Dudley cites an instance in which the flash point obtained was considerably too high, owing to the fact that the testing flame was first applied to the centre of the cup.

"'6. The thermometers used should be frequently compared with a standard instrument.

"'7. Draughts should be carefully avoided.'

"Two general methods of heating the oil may be employed. In the first, the oil is placed in a vessel, which is immersed in a second vessel filled with a very heavy oil, which transmits the heat to the oil to be tested. In the second method, the heating flame is applied directly to the cup, or to a sand bath on which the cup rests, the testing cup being protected from draughts. Both methods have their adherents, although the second one seems to be used more extensively for the high flash test oils. The author has found the New York State Board of Health Tester, used with cover removed, very satisfactory. This tester is of the first class, using a bath in which the testing cup proper is placed."

Mr Skinner states that although there is a general belief that oil as a body is very inflammable, quite the reverse is true. As a simple and safe means of proving this, he suggests that a "blow-torch be turned directly upon the surface of a body of oil having a flash test of 175° C. or more, and the oil will not take fire for some time—in fact, not until the burning or 'fire test' temperature of the oil is reached. A burning brand may be thrust into the oil, and the fire is extinguished as effectually as if the brand were plunged into water. White-hot iron may be thrust into the oil and the iron is cooled, but the oil does not take fire, provided the iron is plunged beneath the surface. The use of oil in oil switches proves that it is a very effective means of putting out the arc. When a fire does occur, it may be easily put out if the supply of air can be shut off from the burning body of oil. It should be remembered, however, that material saturated with oil takes fire very readily, this being due to the fact that a small amount of the material, when coming in contact with the flame or spark, is heated to a temperature above the burning point of the oil and takes fire, the blaze thus started continuing to heat the surrounding material to the burning temperature.

"A precaution which should always be taken in the use of oil, is to eliminate, as far as possible, all fibrous or porous materials which are not actually immersed in the oil, and which may become saturated with it."

Mr Skinner says that an evaporation test is "not so necessary as insulation and flash tests, but such a test should be made occasionally on oil which is used for transformer work. A convenient method of making this test is to place a small amount of oil—usually approximately 2 grammes—in a small porcelain crucible, and heat this over a water bath at a temperature of approximately 100° C. for ten or twelve hours, then determine the percentage evaporation by loss in weight."

Since mineral oils evaporate slightly at a temperature somewhat below their flashing point, it is "essential that a transformer oil have a flash test sufficiently high, so that evaporation will not take place at the ordinary running temperature of the transformer. The evaporation test, if made at a temperature approximately 100° C., will also drive off any moisture which may be present in the oil.

In the case of high flash test oils, the evaporation test at 100° C. may therefore show approximately the amount of moisture present in the oil."

Mr Skinner describes an easy and satisfactory method of making a test for moisture in oil, which had been suggested to him by a prominent oil chemist. The test "consists in placing a small amount of oil in a cup, into which is plunged a piece of iron or other metal which is heated to a temperature just below a dull red heat. Any hissing or crackling sound indicates the presence of moisture. Another method of testing for moisture is to place a small amount of anhydrous copper sulphate in a test tube and then fill the tube with the oil to be tested. After thoroughly shaking, a bluish tinge in the copper sulphate will indicate the presence of moisture in the oil.

"It is difficult to determine the exact amount of moisture in oil when the amount is small, and this is usually not necessary, as it is sufficient to know qualitatively whether or not the moisture is present. In making tests for the different percentages of moisture in the oil, it was found necessary to thoroughly dry the oil, then introduce moisture in the form of water in minute quantities in a closed vessel, and very thoroughly agitate the oil so as to disseminate the water through it. This method is not considered entirely reliable, but for testing purposes gave the striking results embodied in the curve of fig. 68 on p. 155 of the previous chapter. It is considered that the form of the curve is correct, but it may be that the percentage amount of moisture present between the testing terminals is not entirely accurate. Check tests, however, gave close results. It will be seen from this curve (fig. 68) that moisture introduced into the oil to the amount of ·06 per cent. reduced the dielectric strength of the oil to about 50 per cent. of the original value when it was known to be free from moisture, and that there was very little further decrease in the dielectric strength due to increasing the amount of moisture, introduced in the form of water."

There is much further valuable information in Mr Skinner's paper, for which the reader would do well to consult the original source. The paper was also reprinted in the May 1904 number of *The Electric Club Journal* (vol. i. p. 227).

CHAPTER XII

THE INSULATING PROPERTIES OF PAPER AND OF THIN SHEETS OF OTHER FIBROUS MATERIALS

PAPER and other fibrous materials are, owing to their close homogeneous texture and even qualities, largely used, either alone or in conjunction with some other material, such as mica. When employed as a backing for mica, the paper need not be of a very fine quality. Manilla, express and bond papers head the list as far as good disruptive and mechanical strengths are concerned, although the so-called red rope paper is probably the most extensively used of all. These four varieties, when coated with good insulating varnishes, are excellent dielectrics. Japanese paper, owing to its extreme thinness and high mechanical strength, is almost invaluable in making tubular insulations, and is excellent as a backing for mica paper. Such mica paper may be cut up into strips, and armature conductors served, tape fashion, with these strips. Horn Fibre is the toughest and best fibrous material that the writers have as yet tested, but it has not yet come into extended use. Leatheroid enjoyed at one time a very extended use, and is still employed to a great extent. Presspahn, owing to its smooth, glossy surface and homogeneous texture, finds a ready sale on the Continent, and when impregnated with linseed oil, rivals fuller board as regards constant disruptive strength, and uniform thickness. Fibres of both the red and the white variety are very useful in some places, but will not stand much continued heating without losing their mechanical strength and becoming brittle. No paper of any sort should be used without being treated with some moisture-proof insulating varnish, either before or after application to the part to be insulated, as it will

otherwise be quite hygroscopic. The present tendency is to abandon reliance upon the insulating property of these fibrous materials, and to depend rather upon that of the films of varnishes with which they are impregnated, the paper or fibre being

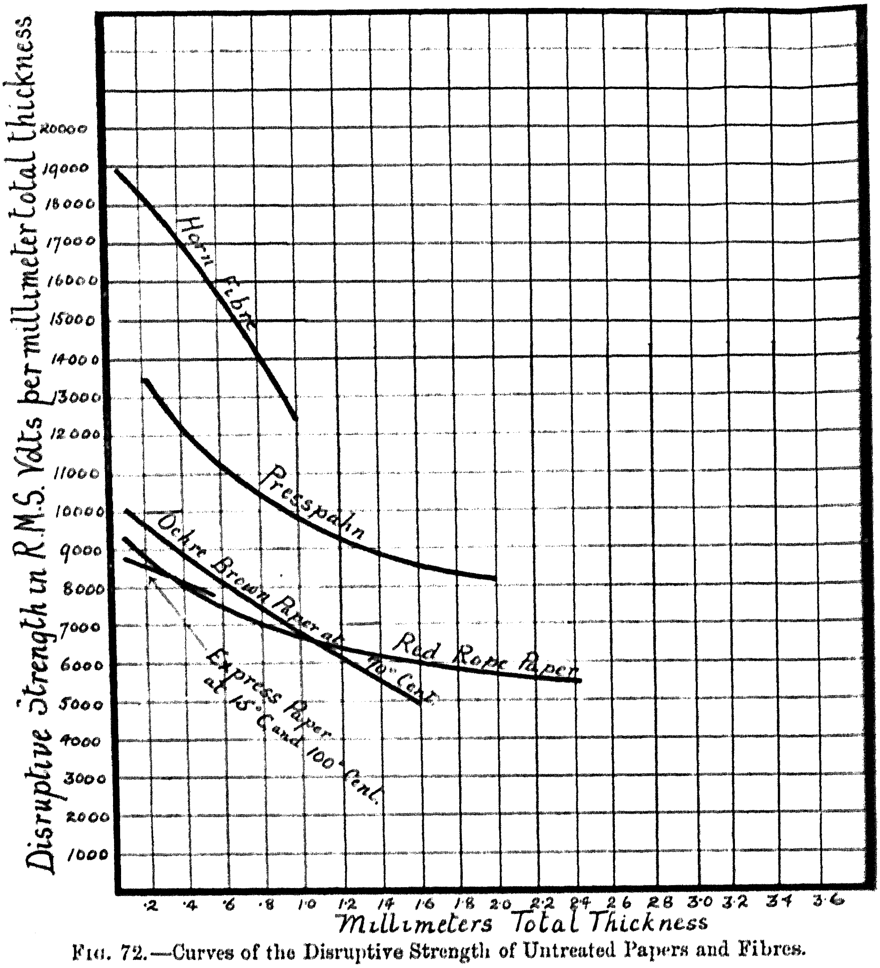


FIG. 72.—Curves of the Disruptive Strength of Untreated Papers and Fibres.

Untreated Materials.—Materials had been dried for 3 hours in a vacuum oven prior to testing.

employed for mechanical reasons.[1] We have investigated the insulating properties of manilla paper, red rope paper, express

[1] "It is well to notice that fibrous materials dipped in insulating compound rarely add their full breakdown strength to that of the varnish, and it is as well to look upon the material as only a medium of applying the insulating varnish."—"On Insulation," *The Elec. Engr.* for September 16, 1904, p. 412.

paper, ochre brown paper, presspahn, and horn fibre, but it is difficult to distinguish between the effect of the use of the different papers, and of the different varnishes with which they are impregnated.

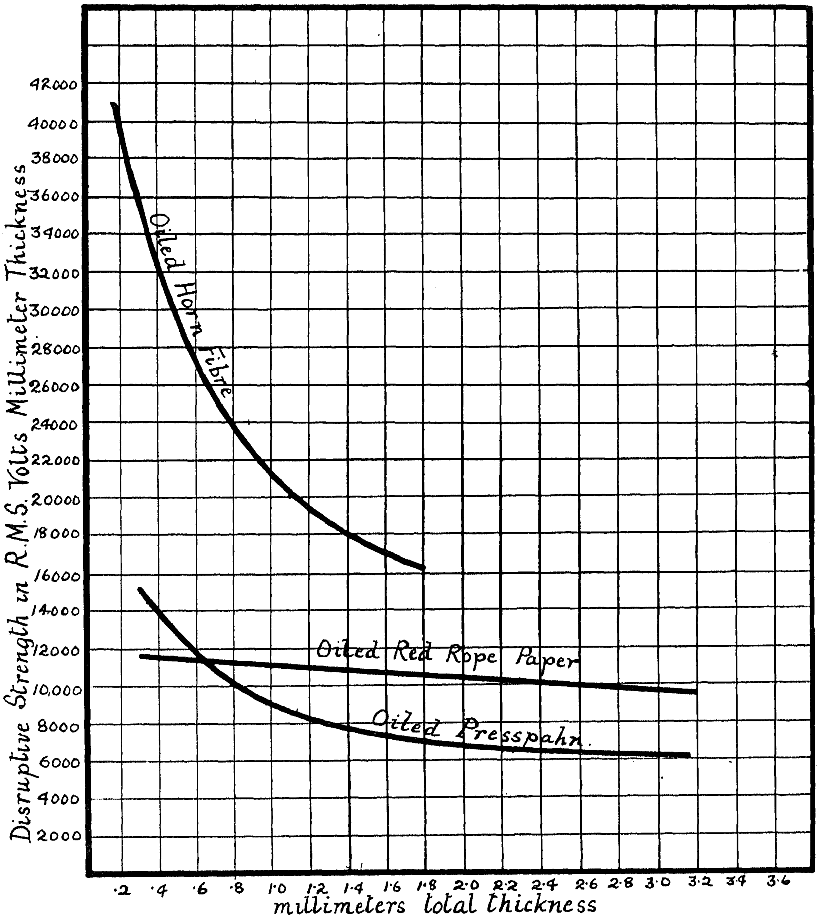


FIG. 73.—Curves of the Disruptive Strength of Impregnated Papers and Fibres. Material had been first dried in a vacuum oven and then soaked in hot linseed oil for 8 hours, and then dried again for 3 hours in a vacuum oven.

In fig. 72 are brought together (plotted to mm. total thickness as abscissæ) the results on the untreated, and in fig. 73 the results on the treated samples. It must be observed that the scale of ordinates in fig. 72 is double that of fig. 73.

In fig. 73 the crossing of the curves for oiled red rope paper and

TABLE XXXIII.—INSULATION TESTS OF "ROPE" PAPER.

Material	Remarks.	Original Thickness in mm.	Thickness after Varnishing.	Volts per 0·01 mm. of Final Thickness.			
				One Layer.	Two Layers.	Three Layers.	Four Layers.
Red rope paper	Taken from stock without drying	0·105	Not varnished.	117	124		
Grey rope paper . . .	„ „ „	0·20	do.	103	96·3		
Red rope paper	„ „ „	0·23	do.	82·5	81·0		
Red rope paper	Dried for 3 hours at 120° Cent. in vacuum oven	0·23	do.	86·8	80·5	75·5	71·5
Red rope paper	Material dipped in "Sticker" and dried 1 hour at 130° C. in vacuum oven, then air-dried over night (16 hours), and then oven-dried (not vacuum) 20 minutes at 212° Cent.	0·105	0·18	360	327		
Grey rope paper . . .		0·20	0·32	155	157		
Red rope paper		0·23	0·32	113	121		
Red rope paper	Same treatment, except dipped in Voltalac .	0·105	0·16	231	277		
Grey rope paper . . .		0·20	0·26	190	139		
Red rope paper		0·23	0·30	151	192		

oiled presspahn is of interest. While in small thicknesses oiled horn fibre has three times the disruptive strength of red paper, it is only about 50 per cent. better when built up to thicknesses of 2 mm.

The tests of ochre brown paper in fig. 72 are taken from

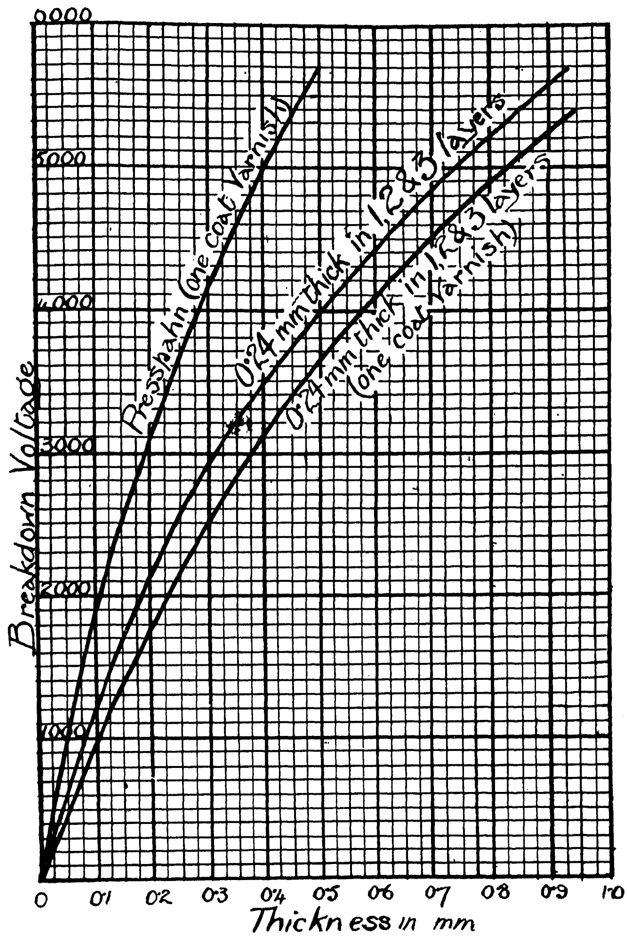


FIG. 74.—Lewis' Curves of the Disruptive Strength of Presspahn.

the mean of the two curves at 15° Cent. and 100° Cent. of fig. 22, p. 37.

In Tables XXXIII. and XXXIV. are given the results of some tests on rope paper and horn fibre, with and without impregnating varnishes.

Each test is the average result for a number of samples.

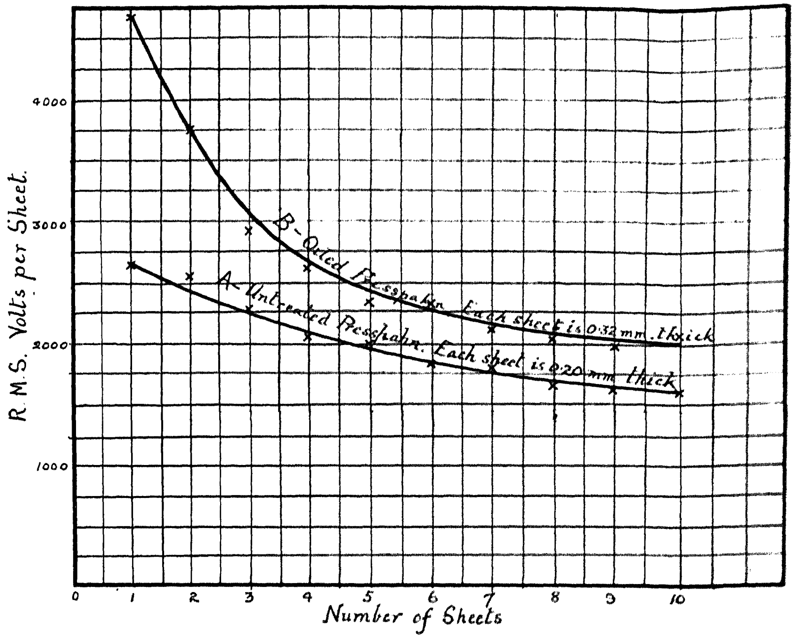


FIG. 75.—Curve showing the Disruptive Strength of Presspahn as a Function of the Number of Sheets.

These samples were first dried in a vacuum oven. Samples B were afterwards soaked for 24 hours in double-boiled linseed oil.

Each point is the average of several tests.

TABLE XXXIV.—INSULATION TESTS OF "HORN FIBRE."

Remarks.		Original Thickness.	Thickness after Varnishing.	Volts per 0·01 mm. of Final Thickness. One Layer.	Volts per 0·01 mm. of Final Thickness. Two Layers.
Taken from stock without drying		0·56	Not varnished	107	105
Dried 3 hours at 120° Cent. in vacuum oven		0·56	Not varnished	123	111
Material dipped in varnish and dried 1 hour at 130° Cent. in vacuum oven, then air-dried over night (16 hours), and then oven-dried (not vacuum) 20 minutes at 212° Cent.	Varnish was "Sticker"	0·56	0·66	133	129
	Varnish was "Voltalac"	0·56	0·74	117	135

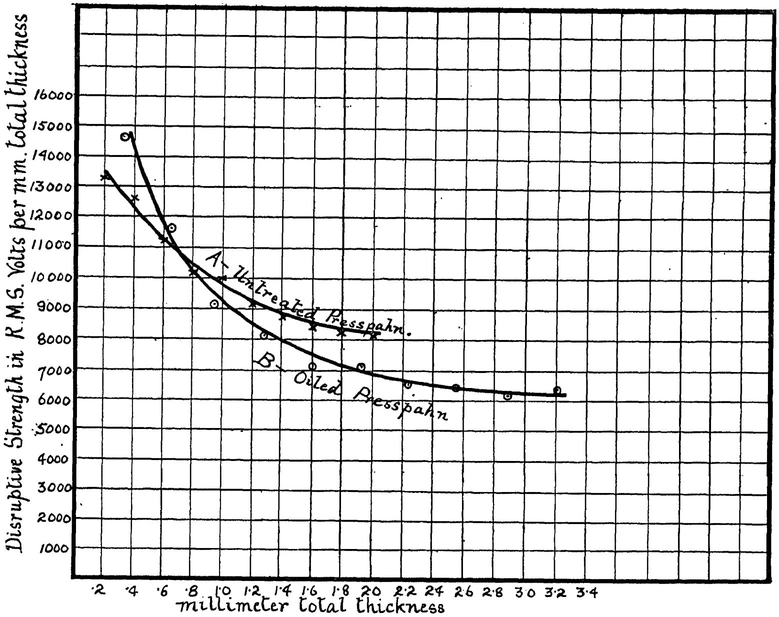


FIG. 76.—Curves of Disruptive Strength of Presspahn when Untreated and when Impregnated.

These samples were first dried in a vacuum oven. Samples B were afterwards soaked for 24 hours in double-boiled linseed oil.

TABLE XXXV.—HOLITSCHER'S RESULTS FOR THE DISRUPTIVE STRENGTH OF PRESSPAHN SUPPLIED BY SEVEN DIFFERENT FIRMS, WHEN COLD AND WARM, WHOLE AND CREASED, AND FOR ITS RATE OF ABSORBING MOISTURE.

Firm.	Disruptive Voltage (tested between plates). Cold		Warm.	Increase in Weight after 24 hours' immersion in water.
	Whole.	Creased.	Whole.	
A.	12,000	8,000	10,000	
B.	11,000	11,000	11,000	
C.	22,500	8,500	20,000	
D.	17,000	8,800	14,000	
E.	11,000	7,500	9,200	83·5 per cent.
F.	13,500	8,800	8,600	65·0 per cent.
G.	15,800	9,500	15,500	15·0 per cent.

Holitscher (*E.T.Z.*, 1902, p. 171) gives the results reproduced in Table XXXV. of tests of materials of the presspahn type, as supplied by seven different firms. All the samples were 1 mm. thick.

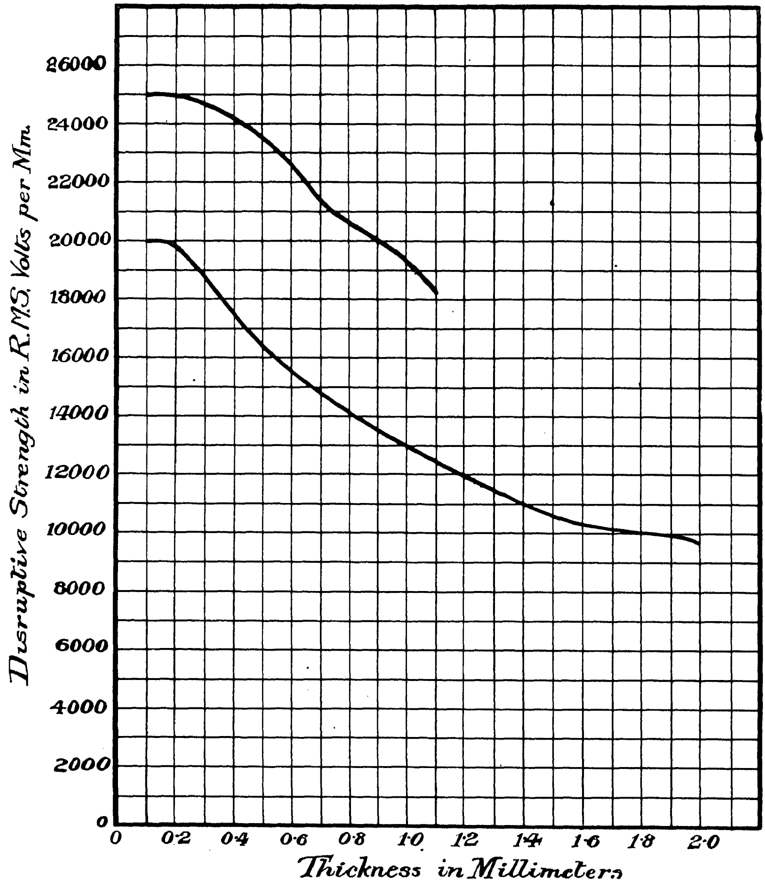


FIG. 76A.—Symons' Curves for the Disruptive Strength of two Samples of Presspahn. Tests were made at 50 cycles.

The results of some other tests on presspahn [1] are plotted in fig. 74. The results of some of our own tests on presspahn are plotted in the curves of figs. 75 and 76, and they lead to a rather interesting point. When, as in fig. 75, the "number of sheets" is used for

[1] From a paper by L. A. Lewis, entitled "Notes on the Commercial and Experimental Testing of Continuous-Current Machinery," read before the Students' Section of the Institution of Electrical Engineers on March 16, 1904.

abscissæ, the oiled presspahn has throughout a higher disruptive strength, as expressed in volts per sheet. But in fig. 76 the same tests are plotted with "mms. total thickness" for abscissæ, and "disruptive strength in volts per mm." as ordinates, and it is found that the oiled presspahn has actually a lower disruptive strength than the untreated presspahn for thicknesses above 0·7 mm. Presspahn is the only material in which we have found

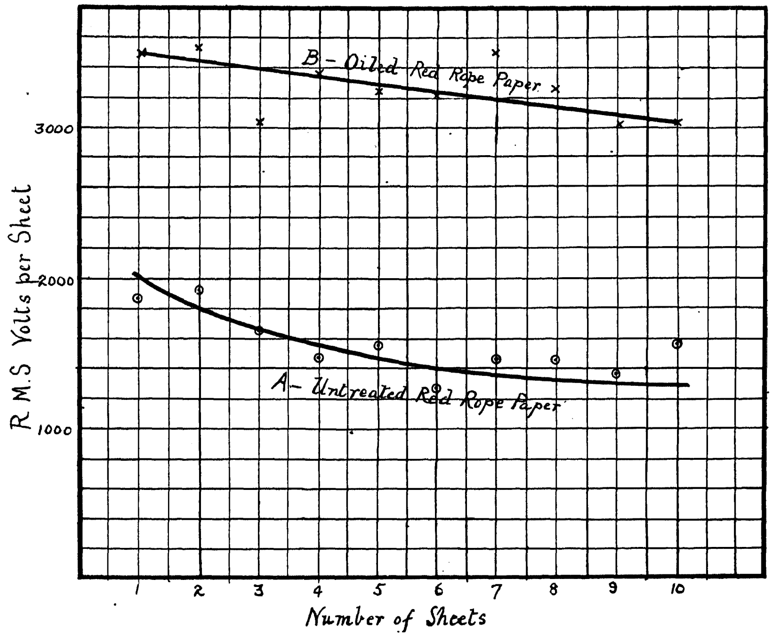


FIG. 77.—Curves of Disruptive Strength of Red Rope Paper when Untreated and when Impregnated, the results being expressed as a function of the number of sheets.

Prior to the tests the sheets had been dried in a vacuum oven. Those for Curve B had also been soaked in hot linseed oil for 18 hours, and then dried again for 3 hours in a vacuum oven.

The untreated sheets were 0·23 mm. thick. The treated sheets were from 0·28 to 0·32 mm. thick, the total of 10 sheets giving a measured thickness of 3·2 mm.

Each point is the average result of several tests.

inferior results when impregnated as compared with the tests when untreated, although the advantage due to impregnating is apt to be overestimated when tests plotted in terms of the "number of sheets" are alone considered, as this makes no allowance for the increase of thickness which results from the process of

impregnating. Symons'[1] results on two samples of presspahn are given in the two curves of fig. 76A.

In the curves of figs. 77 and 78, relating respectively to red rope paper and horn fibre, the gain due to the impregnating varnish is far greater than in the case of presspahn. It is important to

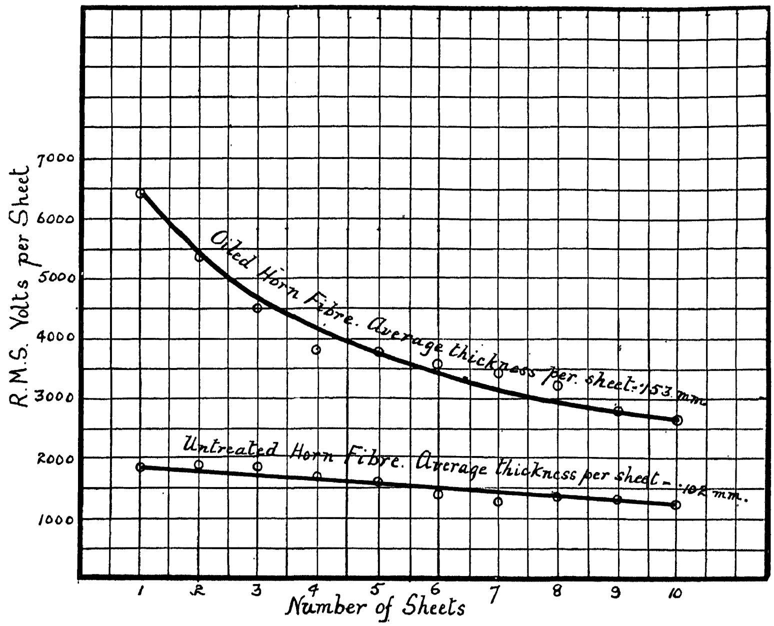


FIG. 78.—Curves of Disruptive Strength of Horn Fibre, when Untreated and when Impregnated.

These samples were first dried in a vacuum oven; they were then soaked for 18 hours in double-boiled linseed oil, maintained just below boiling point, and then again dried in a vacuum oven.

ascertain for the case of each material the particular impregnating varnish which gives the best combined result.

A curve for untreated express paper is given in fig. 79. These tests appeared to show that express paper has the same disruptive strength throughout a wide range of temperatures.

[1] "Insulation and Insulators," H. D. Symons. (Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.)

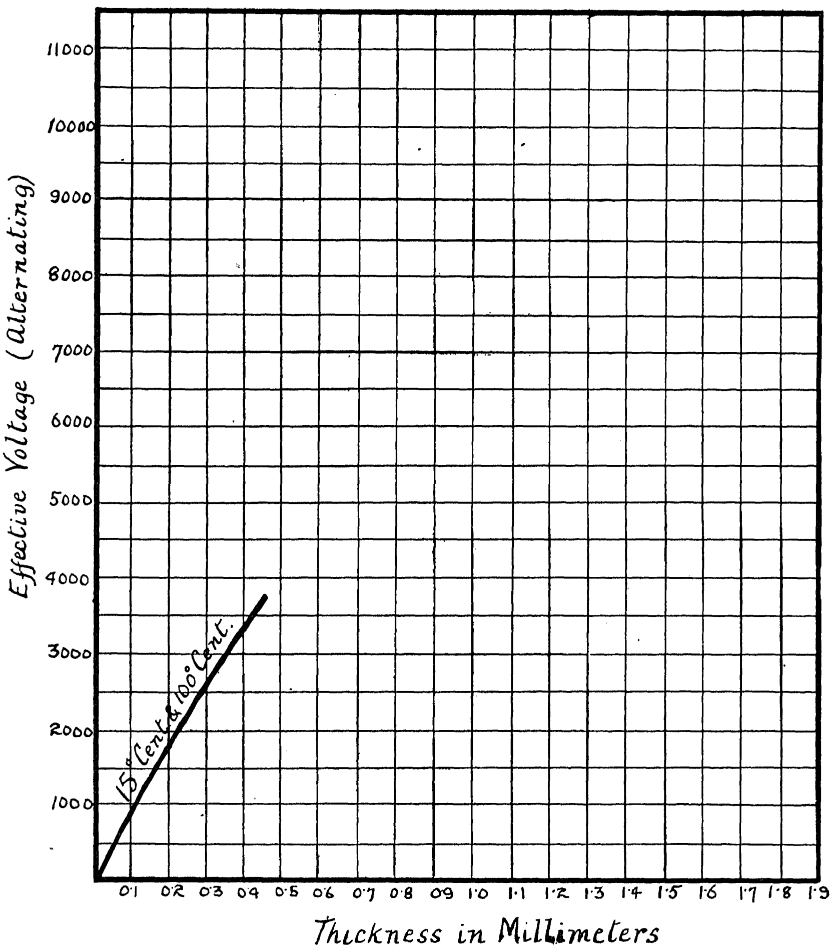


FIG. 79.—Curve of Disruptive Strength of Untreated Express Paper (3d. per lb.). Plotted from a curve in which each point was a mean of five tests.

CHAPTER XIII

IMPREGNATED CLOTHS AND FABRICS

In the present state of the art of making insulations, cloths and fabrics are, as a rule, almost indispensable. These serve as a framework to hold the skin or film of insulating varnishes, so that the thickness, texture, and mechanical strength play a large part in the selection of proper materials to be coated with varnishes.[1] Cambric, muslin, lonsdale, and batiste are the trade names of the best materials for this purpose. Those materials which have the smoothest surface and are the most free from nap and fuzz are to be recommended, and to obtain the best results the cloth should be

[1] "With regard to insulating fibres, papers, and tapes, we know that some depend on the nature of the material for their insulating properties, whilst in others this is merely a medium for carrying an insulating 'varnish or paint,' and it is on this that the strength of the insulator, as such, depends. This latter class, which also includes a certain variety of tapes, should, as far as the insulating medium is concerned with which they are impregnated, fulfil the conditions enumerated above for paints and varnishes. Regarding fibres and papers in their 'natural' state—*i.e.*, not impregnated with an insulating medium—they might be approved of if they meet the following conditions: (1) they should be tough, yet pliable; (2) should not suffer excessively as insulators should they be creased; they should, as far as it is possible to make them, be non-hygroscopic; (4) should be able to stand all temperatures experienced in practice without charring or reducing their insulating properties; (5) should have high insulation per mil. of thickness, except where their mechanical strength is the principal consideration. It will be obvious from the varied nature of insulating materials, and also from the fact that no one material meets all conditions, that a choice has to be made of such as will best suit the varying conditions of service, both mechanically and electrically. With careful attention to this point considerable reduction in the cost of insulating materials may be effected in the manufacture of various electrical apparatus, though the cheapest insulation is not always the best."—*Elec. Engr.*, September 16, 1904, p. 411.

first ironed, or, better still, singed, to obtain as smooth a surface as possible; otherwise the nap or fuzz projecting through the film of varnish breaks up the continuity, and results in a variable disrup-

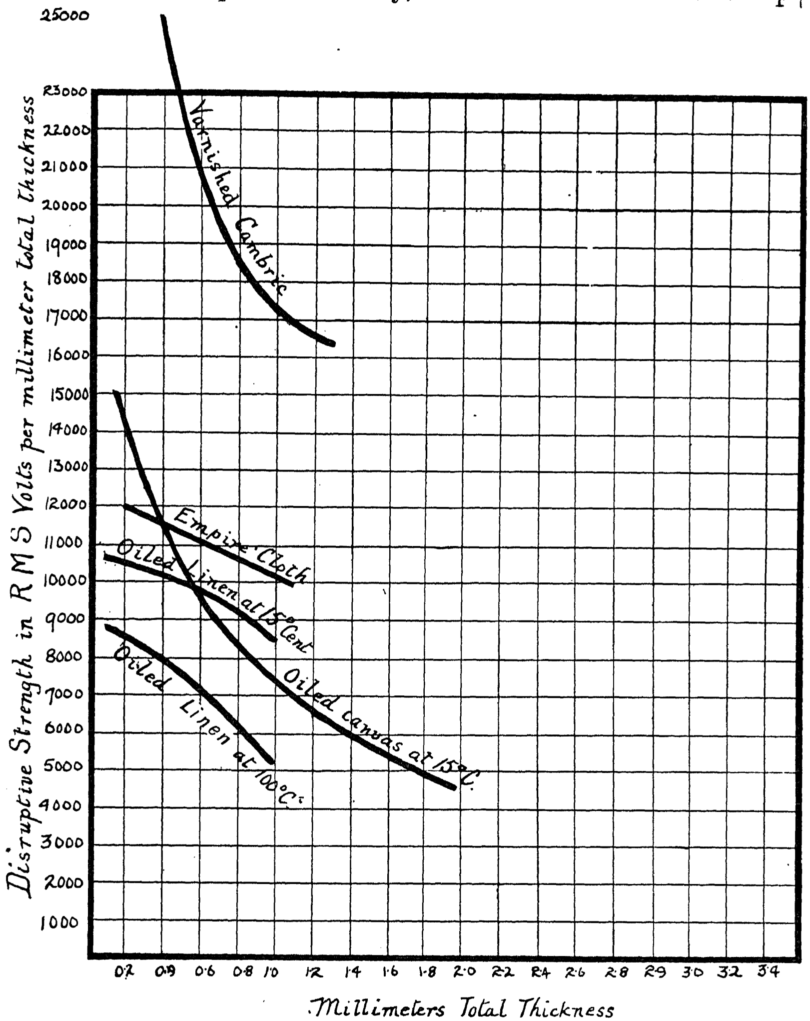


FIG. 80.—Curves of the Disruptive Strength of Impregnated Cloths.

tive strength. The cloth must be free from chlorine, which is used in bleaching, and, when not thoroughly removed, causes fermentation and rotting of the fabric, and prevents the varnish from thoroughly penetrating. To test for chlorine, a sample of the fabric is boiled in distilled water; this water is then put in a test tube,

and a few drops of nitrate of silver solution are added. The appearance of a precipitate indicates the presence of chlorides. There are several different methods of treating cloth with insulating varnishes. Some are crude, and require but little more than a can

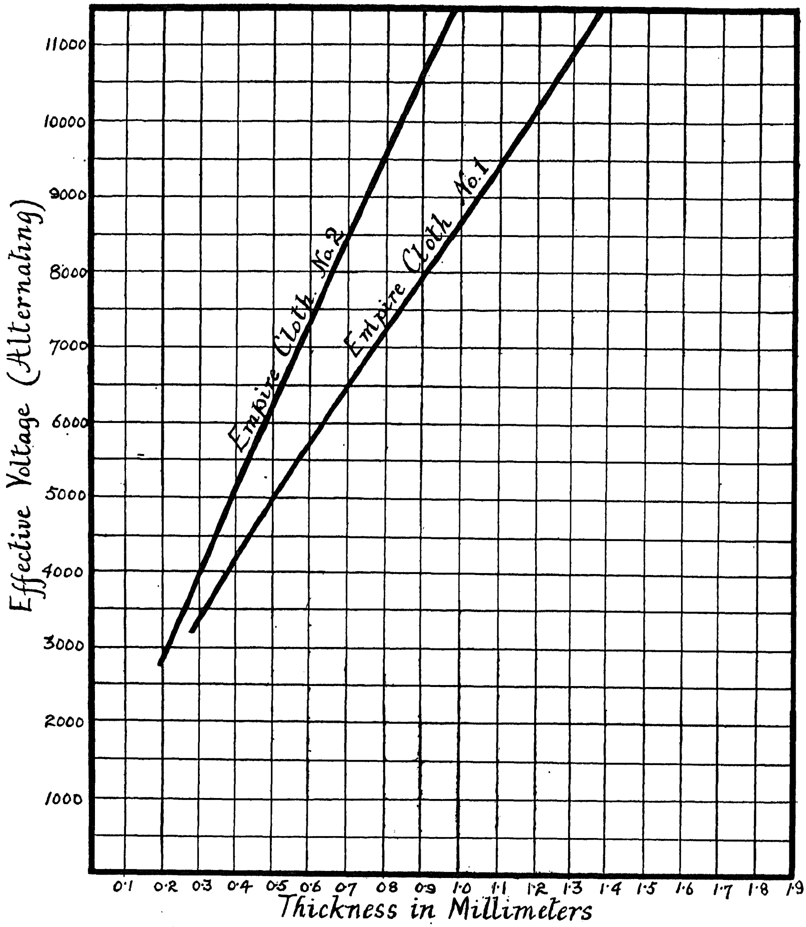


FIG. 81.—O'Gorman's Curves for the Disruptive Strength of Empire Cloth.[1]

of varnish, a paint-brush, and a few clips to hang up the cloth while drying. The cloth is laid on a bench several layers deep and painted over with the brush, the varnish penetrating through to the next layer, which is again treated in its turn. In other cases the cloth is first stretched on a frame and placed in an oven to

[1] Empire Cloth is a trade name employed for a cambric treated with linseed oil by certain processes.

extract the moisture. The varnish is afterwards painted on with a brush and dried, this operation being repeated until the requisite dielectric strength has been acquired. Another method consists in passing the roll of cloth through a trough containing linseed oil, the cloth having first been dried in an oven. The cloth is then again dried, and the linseed oil makes a foundation on which the insulating varnishes spread themselves evenly. An economical

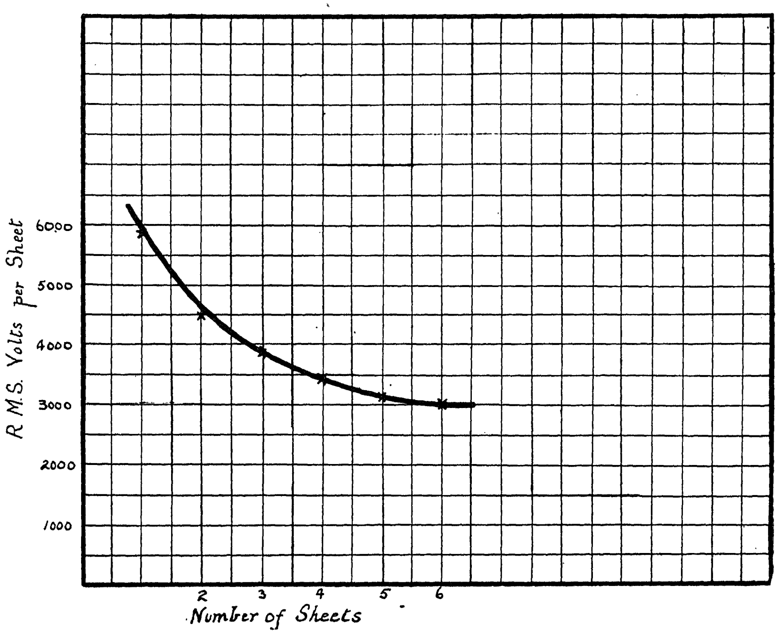


FIG. 82.—Curve of the Disruptive Strength of Varnished Cambric.[1] Thickness per sheet, 0·18 mm.
Each point is the average of several tests.

way is to build an oven, chimney fashion, with a vat of varnish at the bottom. The cloth is drawn through this vat and passes up the chimney very slowly, the chimney being lined with steam pipes, so that the ascending heat quickly dries out the cloth. At the top of the chimney is a roll over which the cloth passes and then descends again. The varnishing operation is then repeated, and after the final drying, the cloth passes on to a roll on which it

[1] Varnished Cambric is a term sometimes used for cambric impregnated with linseed oil, and is then identical with Empire Cloth. However, it sometimes denotes cambric treated with one or other of the well-known insulating varnishes.

is wound in the finished state. This method requires power, and is somewhat expensive, although the expense is generally more than offset by the economy resulting from systematic manufacture. This or some equivalent method is essential when production is on a large scale.

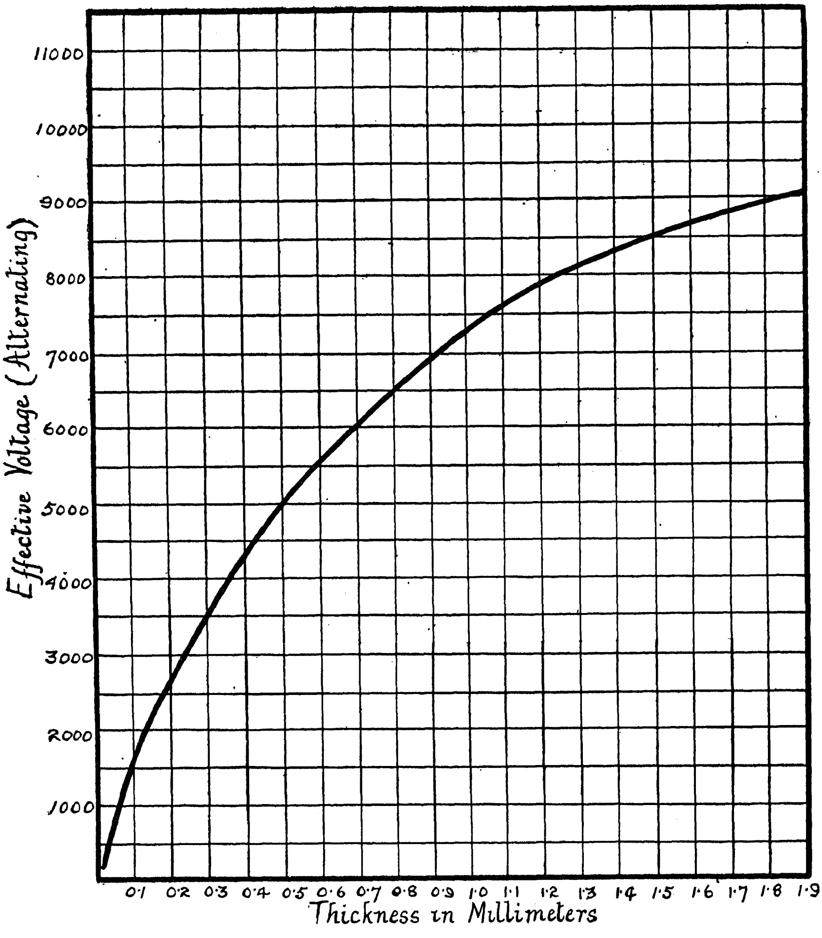


FIG. 83.—Dr Thomson's Curve for the Disruptive Strength of Oiled Canvas.

Another method of applying insulating films is to flood a section of cloth with a sluggishly flowing compound. This is ironed on to the cloth by hot rollers. By this method the mechanical strength of the cloth is not in any way injured. The method is, however, rarely employed.

The Insulating Properties of Impregnated Cloths and Fabrics.

The materials investigated comprised—

Oiled Linen.

Oiled Canvas.

Empire Cloth (a trade name for certain qualities of oil-treated cambric).

Varnished Cambric.

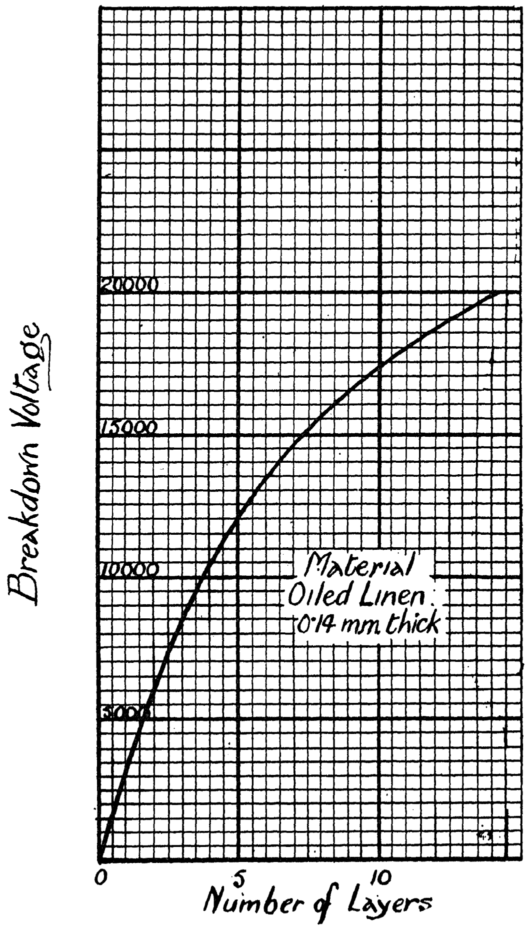


FIG. 84.—Lewis' Curve for the Disruptive Strength of Oiled Linen.

The disruptive strength of impregnated cloths generally falls off rapidly with increasing temperature. This has already been

shown in fig. 23, p. 38, for the case of oiled linen. For this material the curve for 15° Cent. and 100° Cent. are alone reproduced in fig. 80. The curve for "Empire Cloth" in fig. 80 is from the mean of the two curves of fig. 81. Another typical instance of the behaviour of impregnated cloths is given in the curve

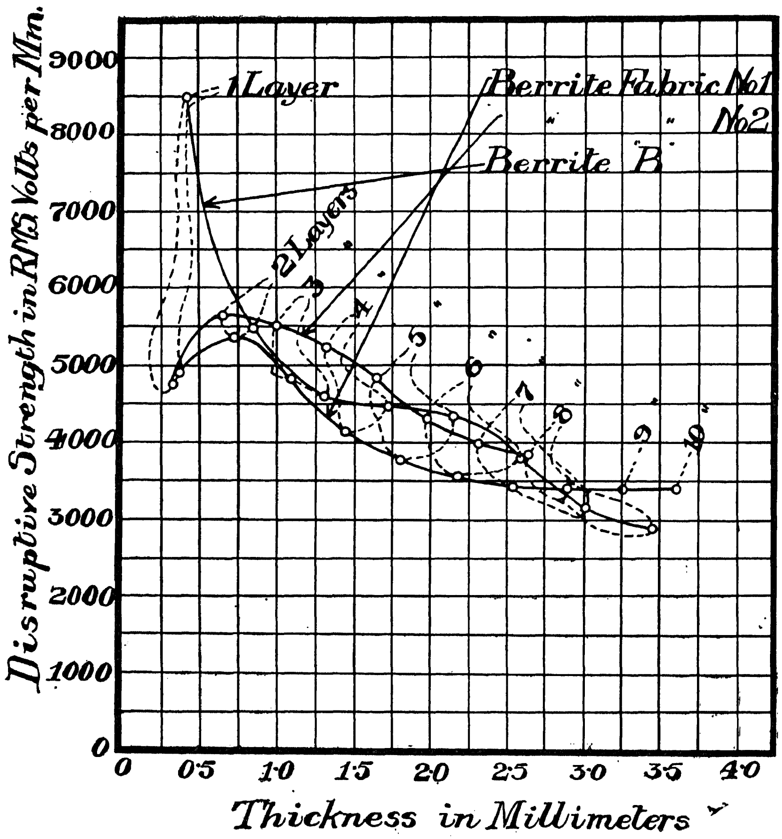


FIG. 84A.—Symons' Curve for the Disruptive Strength at a Periodicity of 83 Cycles per second, of two samples of "Berrite Fabric" and one sample of "Berrite."

of fig. 82, representing the results of tests made on Varnished Cambric.

In the following tables are given some test results on various cloths with and without impregnating varnishes.

Each record is the average result of a number of samples.

TABLE XXXVI.—INSULATION TESTS OF 8-OZ. COTTON DUCK.

Remarks.	Thickness per Layer, mm.	Volts per 0·01 mm. of Thickness.	
		One Layer.	Two Layers.
Taken from stock without drying	0·56	25·0	22·8
Dried 3 hours at 120° Cent. in vacuum oven	0·56	27·7	23·6

TABLE XXXVII.—INSULATION TESTS OF VARNISHED CAMBRIC.

Remarks.	Thickness per Layer.	Volts per 0·01 mm. of Thickness.		
		One Layer.	Two Layers.	Three Layers.
Taken from stock without drying	0·175	405	328	314
	0·250	278	280	
Dried 3 hours at 120° C. in vacuum oven	0·25	328	270	
	0·28	360	268	214

TABLE XXXVIII.—INSULATION TESTS OF SAILCLOTH.

Remarks.	Thickness per Layer.	Volts per 0·01 mm. of Thickness.	
		One Layer.	Two Layers.
Taken from stock without drying	0·80	22·8	21·2
Dried 3 hours at 120° C. in vacuum oven	0·80	33·2	41·9

TABLE XXXIX.—INSULATION TESTS OF 6-OZ. COTTON DRILL.

Remarks.		Original Thickness.	Thickness after Varnishing.	Volts per 0·01 mm. of Final Thickness.	
				Single Layer.	Two Layers.
Taken from stock without drying		0·52	Not varnished	24·5	20·7
Dipped in varnish and dried for 1 hour at 130° Cent. in vacuum oven, then air-dried over night (16 hours), and then oven-dried (not vacuum) 20 minutes at 212° Cent.	Varnish was "Sticker"	0·52	0·67	38·0	36·8
	Varnish was "Voltalac"	0·52	0·60	29·2	20·4

TABLE XL.—INSULATION TESTS OF BLEACHED COTTON CLOTH.

Remarks.		Original Thickness.	Thickness after Varnishing.	Volts per 0·01 mm. of Final Thickness.	
				Single Layer.	Two Layers.
Taken from stock without drying		0·17	Not varnished	35·4	36·0
Dipped in varnish and dried for 1 hour at 130° Cent. in vacuum oven, then air-dried over night (16 hours), and then oven-dried (not vacuum) 20 minutes at 212° Cent.	Varnish was "Sticker"	0·17	0·44	103	95·5
	Varnish was "Voltalac"	0·17	0·28	186	150

In figs. 83 and 84 are given curves for oiled canvas and oiled linen respectively. These two curves have been given out by Dr Thomson[1] and by Lewis.[2] In fig. 84A are given three curves of

[1] *Design of Dynamos*, p. 73.

[2] "Notes on the Commercial and Experimental Testing of Continuous-Current Machinery." A paper presented to the Students' Section of the Institution of Electrical Engineers on March 16, 1904.

the disruptive strength of "Berrite Fabric" derived from data contained in Symons' paper entitled "Insulation and Insulators."[1]

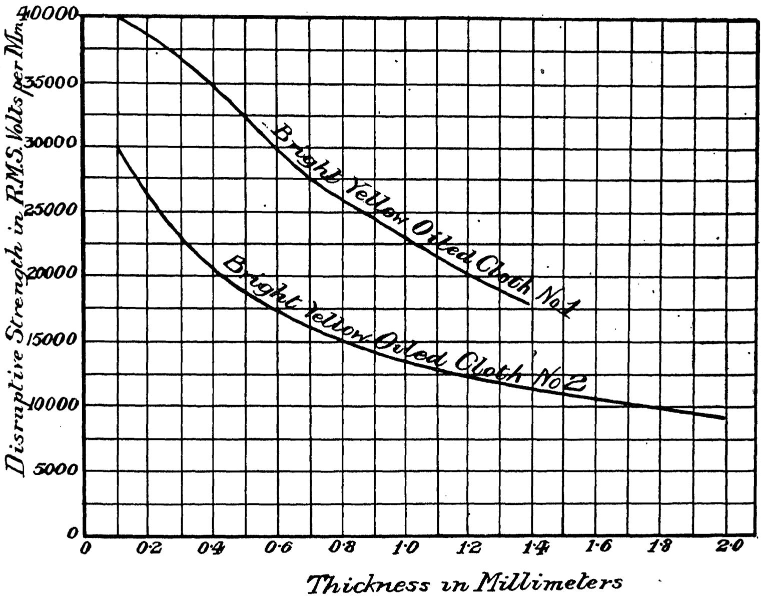


FIG. 84B.—Symons' Curves for the Disruptive Strength of two samples of Yellow Oiled Cloth. Tests were made at 50 Cycles.

"Berrite Fabrics" No. 1 and No. 2 contain powdered mica, and it has been suggested that this may account for the peak in the curves. The curve for bright yellow oiled cloth given in fig. 84B is taken from the same article.

[1] Paper read before the Students' Section of the Institution of Electrical Engineers, April 27, 1904.

CHAPTER XIIIA

THE INSULATING PROPERTIES OF CELLULOID

THE writers have made tests upon the insulating properties of celluloid. The first investigations related to sheets of a clear variety with a thickness of 0·25 mm. Fifty samples were prepared and were baked for 24 hours at 100° Cent., and were then allowed to cool before testing. The tests were made on a 100-cycle circuit, and in each case the duration of the application of the voltage was one minute. The procedure in testing was as follows:—Five samples were subjected to a certain low voltage for one minute, and a record was made of the number of samples remaining unpunctured. The potential was then increased by 500 volts and again applied to the samples for one minute, and tests at higher and higher voltages were successively made, until all the five samples had been punctured. The same procedure was then repeated with five fresh samples, and this was continued until five sets of tests of five samples each had been made; twenty-five samples in all were punctured. These tests were made at 20° Cent. A similar set of tests on the other twenty-five samples was made at 100° Cent. The results for these fifty samples are set forth in Table XLA.

From the results of the tests recorded in Table XLA., 3500 R.M.S. volts is seen to be a safe working pressure at 20° Cent., and 1500 R.M.S. volts at 100° Cent., or 14,000 and 6000 volts per millimetre respectively. Thus heat brings down the disruptive strength considerably. Specimens after having been heated to a temperature of 100° Cent. have a slightly discoloured appearance as if deterioration had taken place; the material, however, retains its flexibility, and when allowed to cool, regains its insulating property.

TABLE XLA.—TESTS ON CLEAR CELLULOID (Thickness=0·25 mm.).

Temp. of Test.	R.M.S. Volts.	Number of Surviving Samples.				
20°C.	3000	5	5	5	5	5
„	3500	5	5	5	5	5
„	4000	5	5	5	4	5
„	4500	5	5	5	4	5
„	5000	5	5	5	3	5
„	5500	5	4	5	3	4
„	6000	4	1	3	2	2
„	6500	0	0	2	0	0
„	7000	0	0	0	0	0
100° C.	1000	5	5	5	5	5
„	1500	5	5	5	5	5
„	2000	4	4	5	4	4
„	2500	1	1	0	0	1
„	3000	0	0	0	0	0

Similar tests were made at 20° Cent. on two each of thirteen variously coloured samples. The colouring matter appears to have had some influence. The thickness appears to have had but little influence. The range of thickness is, however, so slight as to render it difficult to draw conclusions as to the extent of its influence. These specimens were not baked before testing as in the case of the clear variety. The results are set forth in Table XLB.

For the average of the thirteen varieties, the disruptive strength of the weakest of the two samples of each kind tested works out at 19,400 R.M.S. volts per millimetre at 20° Cent., as against the 14,000 R.M.S. volts for the clear variety first tested. It would have appeared probable that the preliminary baking at 100° Cent. for 24 hours had permanently lowered the disruptive strength of the clear samples, but further tests indicated that the clear samples suffered no permanent injury by prolonged heating at 100° Cent., regaining their original disruptive strength when again cool.

A specimen was soaked in water for 27 hours with the following result:—

Weight before soaking	32·8	grammes.
Weight after soaking	33·4	„
Weight per cubic centimetre	1·44	„

TABLE XLB.—TESTS ON COLOURED SAMPLES OF CELLULOID.

Number of Samples surviving One Minute's Application of the Testing Voltage.

Designation of samples	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
Millimetres thickness of samples	0·147	0·167	0·218	0·223	0·231	0·236	0·254	0·254	0·254	0·254	0·276	0·290	·292
Colour of samples	Opaque White.	Light Vermilion.	Flesh Colour.	Cobalt Blue.	Ultra Marine.	Violet.	Dark Blue.	Light Green.	Red.	Mottled White.	Light Blue.	Gold.	Opaque White.
R.M.S. Voltage. 1000	2	2	...	...	...	...	...	...	...	...	...	...	...
1500	2	2	...	...	...	...	...	...	...	...	...	...	...
2000	0	2	...	...	...	...	...	...	...	...	...	...	...
2500	...	2	2	2	2	2	2	2	2	2	2	2	2
3000	...	2	2	2	2	2	2	2	2	2	2	2	2
3500	...	2	2	2	2	2	2	2	2	2	2	2	2
4000	...	2	2	2	2	2	2	2	2	1	2	2	2
4500	...	1	2	2	2	2	2	2	2	1	2	2	2
5000	...	1	2	2	1	0	2	2	0	0	2	2	2
5500	...	1	2	0	0	...	1	1	...	...	2	2	2
6000	...	0	1	...	...	...	0	0	...	...	0	2	1
6500	...	...	0	...	...	...	...	...	...	...	...	2	1
7000	...	...	...	...	...	...	...	...	...	...	...	0	0
Voltage piercing first of the two samples	1500	4000	5500	5000	4500	4500	5000	5000	4500	3500	5500	6500	5500
Voltage piercing second of the two samples	1500	5500	6000	5000	5000	4500	5500	5500	4500	4500	5500	6500	6500
Disruptive strength of weakest sample in volts per mm.	10,200	24,000	25,200	22,400	19,500	19,100	19,700	19,700	17,700	13,800	20,000	22,400	18,900

PRICE.—In sheets 51 cms. by 124 cms.

	Per cubic cm.	Per kg.
0·13 mm. thick	·467d.	£1 7 1
0·25 to 0·75 mm. thick	·281d.	0 16 2
1·0 to 1·5 mm. thick	·246d.	0 14 2

Celluloid softens in boiling water and may then be moulded or pressed into various forms. Its specific gravity is 1·44. A sample 0·26 mm. thick, and measuring 60 mm. by 60 mm., was tested in a hydraulic press, first with 40 tons while cold, and afterwards with 80-tons pressure while heated to 80° Cent., or a pressure of 2200 kgs. per sq. cm., and the three dimensions were unchanged. Other tests on a strip measuring 30 mm. by 30 mm. showed that the thickness increases slightly on heating, the other dimensions decreasing. If the sheet of celluloid is pressed between the pages of a book with an edge projecting, the projecting celluloid will burn quietly when ignited, until the projecting edge is burned away, when it extinguishes itself, leaving the remainder uninjured. On account of these properties it has been suggested that the use of celluloid as a component of the insulation between commutator segments would not be altogether out of the question.

CHAPTER XIV

THE INSULATING OF GROUPS OF CONDUCTORS IN ARMATURE SLOTS

In order to obtain a high "space factor" in armature slots, it is essential not only to select the very best of materials for the insulation of the groups of conductors, but careful attention must also be given to the order of their arrangement, so that those suitable for withstanding mechanical strains shall be so disposed as to shield the mechanically more delicate, but dielectrically stronger materials. We must consider the reasons leading to the use of particular materials in various cases.

It has for many grades of work been found preferable in practice that a tough, fibrous material, suitably treated to render it moisture-proof, should come next to the iron walls of the slot, in order to protect from mechanical injuries, the conductors and their high-grade insulating wrappings. Nevertheless, where motors are manufactured in quantities, the slot lining is often dispensed with, and the form-wound coil, after being hydraulically compressed, is forced into the un-lined slot.

The following materials have thus been employed for slot linings. They are arranged in the order of their toughness:—

Horn Fibre.	Presspahn.
Leatheroid.	Red Rope Paper and Manilla Paper.

These and similar materials may be obtained of almost any thickness. It is generally preferable to use several layers of thin material in making up a slot lining of a required thickness. Thus, for example, sheets of presspahn, each 0·25 mm. thick, used in two or three layers, are far more flexible and give a somewhat higher total disruptive strength than single sheets of equivalent thickness. There is less danger of cracking the material at the bends, and if faults

exist in the component sheets, the danger of their being superposed is less the greater the number of sheets. Each sheet may also be more thoroughly dried out the thinner it is. One also avoids the necessity of keeping in stock a large number of different thicknesses.

Horn Fibre ranks first, both in mechanical and in disruptive strength, but does not run very uniform in thickness. It is also relatively expensive.

Presspahn ranks first in uniformity of thickness and in surface smoothness; it is tough mechanically, and has high disruptive strength.

Red rope paper and manilla paper are cheap, and are widely used for slot linings, but care must be taken to test the quality. Manilla paper is preferable.

When wood is used in armature construction it must be dried with the greatest care and made waterproof by suitable treatment. It is often used for the retaining wedges for the slot conductors, but has the disadvantage that when so employed it will, in the interests of mechanical strength, require more space than is necessary by other arrangements and materials. It obstructs the emission of heat from the conductors. It is also difficult to avoid warping and cracking. It necessitates the use of more expensive punches and dies. In general it may be said that the use of wood in armature slots is to be avoided. Formerly it was employed to a great extent. It is preferable to let the insulated armature coils come directly to the surface and be held in place by binding bands.

Great care must be exercised with all slot-lining insulations to subject them to thorough drying and waterproofing processes. The most effective process consists in prolonged soaking in hot linseed oil. When recourse must be had to the use of wood for slot wedges, great care should be employed in the selection and treatment of the wood. It should be of hard, fine grain, as, for example, maple or teak. It must be cut with the grain, and must be free from knots and irregularities of all kinds. It must be thoroughly seasoned and dried. The ultimate drying should be in a vacuum oven, and after being taken from the oven it should, while still hot, be immersed in double-boiled linseed oil, and left there for from twelve to twenty-four hours, the temperature being maintained near the boiling point. The wood thus becomes

thoroughly impregnated, making it moisture-proof and improving its insulating qualities.

Figs. 85 and 86 are instances of the preferable design for armature slots in which wedges are dispensed with. The use of wooden wedges is at present coming to be restricted to the external stators of induction motors with open slots, for in this case use cannot, of course, be made of binding wires. Fig. 87 gives an instance of such a slot.

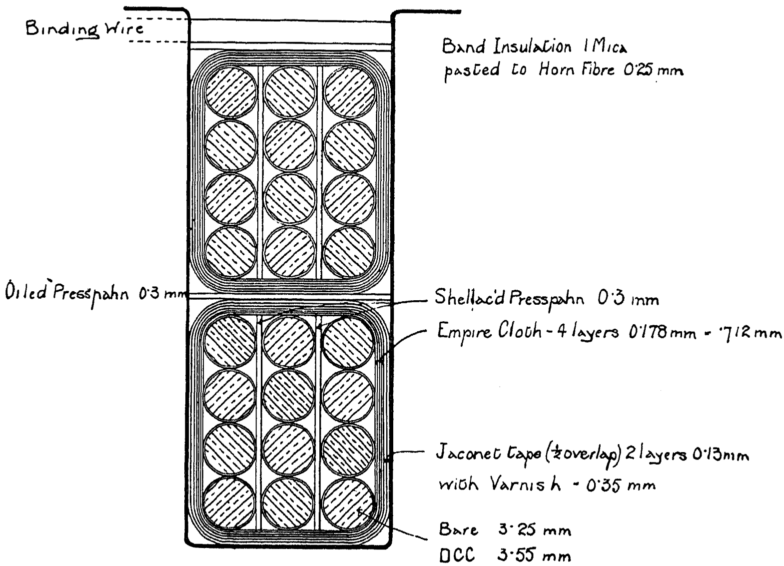


Fig. 85.—Slot Design without Independent Slot Lining.

It is not generally remembered that most papers and some cloths have a grain. By suitable recognition of this circumstance in the treatment and application of papers and cloths, much better results may be obtained, for if, for slot linings, the paper or presspahn is folded with the grain, cracking may be obviated. One can satisfy oneself on this point by simply creasing or bending a piece of red rope paper or presspahn, first in one direction and then crosswise to that direction. The difference in the amount of cracking at the crease will be very apparent.[1]

[1] "We investigate all such materials as paper, oiled linen, etc., not only when flat, but also when weakened by folding or bending; for while many of these materials insulate excellently in the original condition, they may be altogether

Mica and Micanite should only be employed for slot linings in high-voltage machines. Presspahn-mica is another and structurally preferable slot lining for such machines.[1]

For materials to be employed in binding the conductors together in groups, and for the wrapping for armature bars, one or more of the materials given in the following list may be employed :—

Cotton tape (sometimes known as "jaconet" tape, and generally 0·13 mm. thick).

Varnished cambric.

Manilla paper, impregnated with insulating varnish.

Oiled unbleached cotton.

Mica paper.

From this variety a suitable choice will ensure good results if care is used in the preparation and application. A few examples from practice will be of service.

Insulation Specification for 500-*Volt Tramway Motor Armature Slots.*

The conductors are first finely spun with a double cotton covering. This, of course, is generally done by the firm supplying the copper wires.

The wound coils are dried for three hours in a vacuum oven at 90° Cent., and are then impregnated with a good and preferably plastic insulating varnish to render them moisture-proof.

useless, owing to inability to withstand the bending to which they must be subjected in practice."—Holitscher, *E.T.Z.*, 1902, p. 171. "In handling many fibre and paper insulators, it is almost impossible to avoid creasing the sheet, these materials being usually supplied in sheets or rolls. This brings us to the second point regarding this class of material. This creasing, whether accidental or intentional, should not materially weaken the strength of the material as an insulator. Further, creasing 'fibre, presspahn, etc.,' destroys the glazed surface, and this makes the material more hygroscopic, and is thus likely to reduce its insulating value. This class of insulator is naturally hygroscopic, and it is almost entirely on the glazed surface that dependence is made to keep out moisture. Care should be taken to inspect fibrous materials other than woven fabrics, as it sometimes happens that pinholes and very thin places are to be found, and at times small particles of metal, such as filing dust, are rolled into the material. Both of these faults are undesirable, the latter especially so."—"On Insulation," *The Elec. Engr.* for September 16, 1904, p. 412.

[1] For description of presspahn-mica, see p. 199.

In making up the compound coil, pieces of very thin shellac'd presspahn[1] are placed between the component sections. The two straight sides (*i.e.* the slot portion) are then placed in a steam or electrically heated mould, thus compressing the whole group of conductors into a solid compact form.

The slot portion is then wrapped over with from two to four layers of varnished cambric, and then the whole coil is served with "jaconet" tape (cotton tape), 0·13 mm. thick and 16 mm. wide, wound with half over-lap.

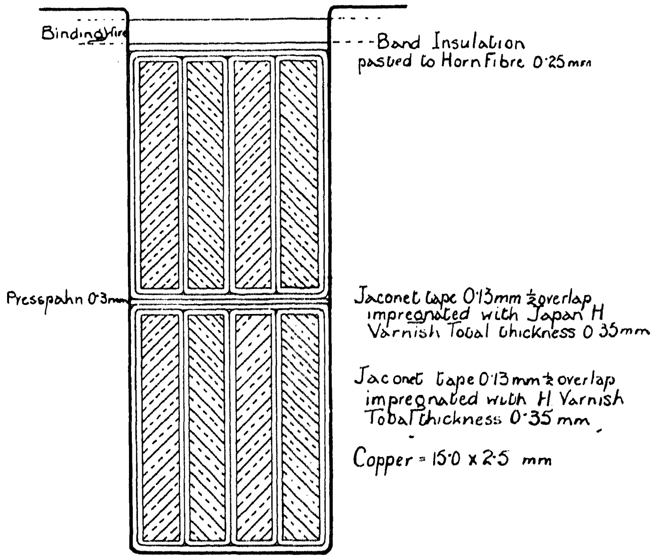


FIG. 86.—Slot Design without Independent Slot Lining.

The coil must next be dried in a vacuum oven and dipped twice in a plastic varnish, and subsequent to each dipping it should be dried for three hours in a vacuum oven at 90° Cent.

After dipping the slot portion in hot paraffin wax, to protect it against possible abrasion during assembling, the coil is ready to be assembled on the armature. The section through this coil assembled in the slot is shown in fig. 85.

[1] Shellac'd presspahn has the advantage for this purpose that the shellac is pressed laterally out between the wires, filling up the interstices and cementing the whole into one compact mass. There is not enough shellac present to be harmful.

When completely assembled on the armature core and bound, such a winding should stand for one minute at 20° Cent. the application of at least 3500 R.M.S. volts from copper to core.

In fig. 86 is shown the slot arrangement for a bar winding with 8 conductors per slot, placed 4 wide and 2 deep. Such a 500-volt bar winding should be tested with at least 3500 volts when connected and completed.

The bars, after being served with "jaconet" tape and thoroughly

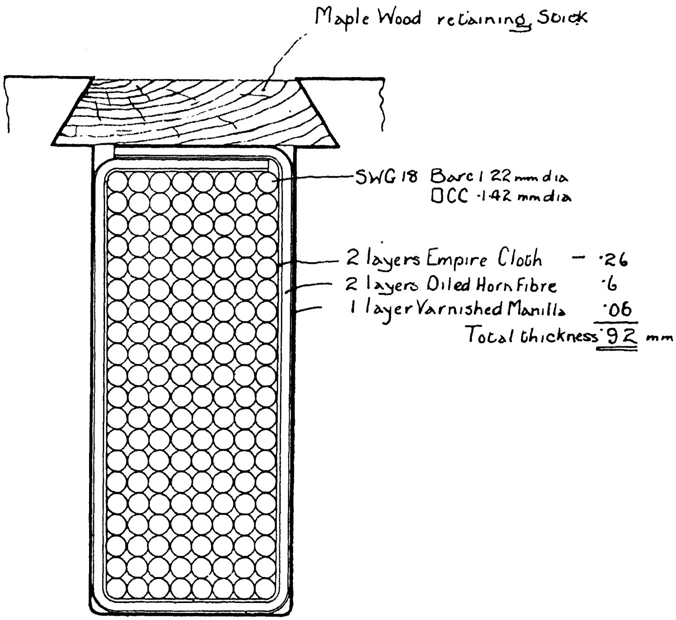


FIG. 87.—Design for Stator Slot.

dried, must be made waterproof by impregnating the tape with some good plastic varnish. After the application of each coat of varnish, the bars must be baked for three hours in a vacuum oven at 90° Cent.

In fig. 87 is given a 500-volt winding for the stator of an induction motor.

For equivalent windings for lower voltages, the insulation can, from mechanical considerations, only be decreased very slightly, since, although the insulation thickness is unnecessarily great for the required disruptive strength, there is great risk of mechanical

weakness with thinner insulations, and this would ultimately entail defective insulation. With this reservation, the above three examples will serve as a guide by which other types and sizes may be constructed. Great care must be taken to ensure the high quality of all the materials employed. A great deal depends upon having the varnishes adjusted to the most suitable consistency.

In the case of alternating current machinery, still greater care should in general be given to the insulation, owing to the higher voltages generally employed, and the lower factors of safety which it is practicable to adopt. When, however, the potential does not exceed 500 volts, the insulation may be very much the same as for continuous-current machines; in fact, the present custom is to permit a much lower insulation standard than for continuous-current machines for the same rated voltage. This is a wrong tendency, and has no possible justification. In fact, for a given rated voltage, the maximum voltage occurring is higher in the alternating current machinery to the extent that the maximum exceeds the R.M.S. voltage.

For voltages above the range of those employed for continuous-current machines, presspahn may in some cases preferably be replaced by horn fibre, owing to its higher mechanical and disruptive strength. Indeed, if manufacturing companies were not so hopelessly involved by tradition and established customs, the better material would more often be used, and with advantage, since any difference in the cost of the insulating material would be of negligible influence on the total cost of the machine. This, however, should not be taken as advocating so wastefully expensive a practice as the use of micanite linings on continuous-current motors of from 250 to 600 volts.

On alternating-current machinery of from 1000 volts upward, a moulded presspahn-mica insulation is very suitable. In such cases some firms employ micanite tubing. This is, however, not only more expensive, but, what is most important, it is more liable to be injured by moisture and dampness, which ultimately permeates the sticking varnish and causes the tube to lose its compactness and become mushy, ultimately disintegrating after long service in damp situations.

Presspahn-mica may be made up as follows :—On a sheet of oiled presspahn 0·2 mm. thick, one layer of flakes of mica is pasted, slightly overlapping, over three-fourths of its surface, a rim equal to one-fourth of the width of the sheet remaining uncovered. This sheet is rolled up over a mandril and baked in a form. The mandril is of the dimensions desired for the inside of the tube. The tube may be sawn open at the top with a circular saw. The slitted tube is inserted in the armature slot, and the wires are fed in through the slit. Before pasting the flakes of mica on the presspahn, the latter should first be dried for 3 hours at 70° Cent. in a vacuum oven, and then placed for 24 hours in a tank of pure, double-boiled linseed oil, the oil being maintained at a temperature somewhat below its boiling point, by means of steam pipes lining the tank. The presspahn should then be removed and dried in an oven or in the air, the former being the quicker process, but otherwise possessing no advantage, in such a case, over drying in air.

A presspahn-mica tube 2·5 mm. thick, consisting of seven layers of presspahn and six layers of mica, when carefully prepared, should have a disruptive strength of 30,000 R.M.S. volts. It has been found that in the construction of micanite tubes the sticking varnishes are the source of much trouble, and they should therefore be used sparingly. The adhesive qualities of the linseed oil with which the presspahn is impregnated, are sufficient, when the tube is warmed up, to be depended upon for the purpose of sticking together adjacent layers. If the ends of the tube are dipped in hot paraffin, it will prevent moisture creeping in between the leaves. Such a presspahn-mica tube constitutes a moisture and acid proof, non-deteriorating insulation, and has the advantage over micanite tubes that the presspahn, being in one continuous piece, holds the other components firmly together. In micanite tubes, moisture penetrating into the sticker leads to disintegration.

Fessenden[1] has described a novel method which he once employed for insulating the armature conductors in a case where very heavy currents were to be carried. He states that it is well known that asbestos and silicate of soda "form a good coating, which is, how-

[1] *Trans. Am. Inst. Elec. Engrs.*, vol. xv., pp. 147 and 148 (1898).

ever, poor mechanically. The armature bars were wrapped with asbestos string and then coated with the silicate. This made, when dry, an extremely firm covering, which could only be removed with a hammer. Though at first a bank of 100 lamps could be lit up through the insulation, after a little running, it dried out to quite a high figure, and the machine did good service, at one time running several hours, as I am informed on good authority, under such an overload that the carbon brushes were red-hot."

CHAPTER XV

THE "SPACE FACTOR"[1]

THE term "space factor" is employed to denote the ratio of actual nett cross-sectional area of copper in a given winding, to the gross cross section of the winding. For armature windings it denotes the ratio of the total copper cross section per slot to the gross

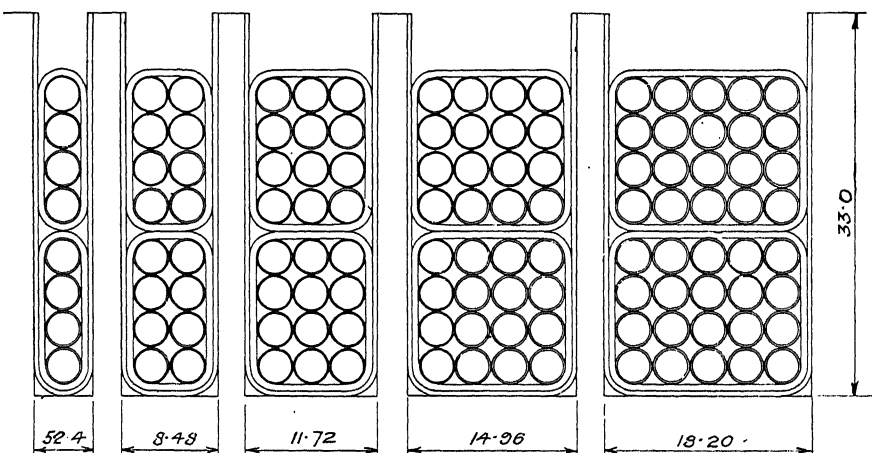


FIG. 88.—Various Arrangements of Equivalent Windings (Round Wire).

area of the slot (*i.e.* to the product of width and depth). The "assembled" width of the armature slot is employed in this case.

Directing our attention first to the question of the space factor of armature slots, we can readily arrive at useful conclusions as to the values obtainable, and as to the proportions and designs leading to high values.

Assume that a certain manufacturer finds by experience that he

[1] This Chapter is based upon an article contributed by one of the authors in 1903 to the columns of *Technics* (vol. i. p. 363).

must, on his 500-volt continuous-current machines, employ a total thickness of 1·15 mm. from copper to iron, and that a standard double-cotton-covered wire should in general be employed. Although the thickness of double cotton covering decreases very slightly with decreasing diameter, it will suffice for our purpose in this chapter to take it as constant at 0·15 mm. This leaves 1·00 mm. insulation to be provided between the iron core and the double-cotton-covered conductor. Suppose this to be made up of a slot lining 0·4 mm. thick, and a coil insulation 0·6 mm. thick. Let us take the case of an armature wound with four turns per commutator segment, of double-cotton-covered No. 11 S.W.G. The bare diameter of No. 11 S.W.G. is 2·94 mm. The double-cotton-covered diameter is 3·20 mm. In fig. 88 are shown arrangements with 1, 2, 3, 4 and 5 segments respectively per armature slot, designed on the above assumptions as to required insulation. The space factors are as shown in Table XLI. and in the lower curve of fig. 90. This shows us that higher space factors may generally be obtained the fewer

TABLE XLI.—"SPACE FACTORS" FOR THE SLOTS AND WINDINGS OF FIGS. 88 AND 89.

Commutator Segments per Slot.	Turns per Segment.	Cross Section One Conductor in Square cms.	Total Number of Conductors per Slot.	Total Copper Cross Section per Slot. (Copper Area.)	Width of Slot. Cms. Fig. 88.	Depth of Slot. Cms. Fig. 88.	Area of Slot. Sq. cms. Fig. 88.	"Space Factor." $\left(\frac{\text{Copper Area.}}{\text{Slot Area.}}\right)$ Fig 88.	For Fig. 89.—Width of Slot and Copper Area remain the same. Depth of Slot 2·8 cms. Area of Slot. Sq. cms. Fig. 89.	For Fig. 89.—Space Factor. Fig. 89.
1	4	·068	8	0·544	0·524	3·3	1·73	·314	1·465	·371
2	4	·068	16	1·09	0·848	3·3	2·80	·390	2·37	·460
3	4	·068	24	1·63	1·172	3·3	3·87	·421	3·28	·498
4	4	·068	32	2·18	1·496	3·3	4·93	·443	4·18	·522
5	4	·068	40	2·72	1·820	3·3	6·00	·454	5·09	·535

the number of slots, *i.e.* the greater the number of conductors concentrated in one slot. This obviously leads to finding space for more copper on a given armature diameter, hence to an increased output, so far as other considerations do not interfere.

TABLE XLII.—"SPACE FACTORS" FOR THE SLOTS AND WINDINGS OF FIGS. 92 AND 93.

Commutator Segments per Slot.	Turns per Segment.	Cross Section of one Conductor. Sq. cms.	Total number of Conductors per Slot.	Total Copper Cross Section per Slot (A).	Width of Slot for Fig. 92. Cms.	Depth of Slot for Fig. 92. Cms.	Width of Slot × Depth of Slot for Fig. 92. Sq. cms. (B.)	"Space Factor" (A ÷ B) for Fig. 92.	Width of Slot for Fig. 93. Cms.	Depth of Slot for Fig. 93. Cms.	"Space Factor" (A ÷ B) for Fig. 93.
1	1	·274	2	·544	·82	2·02	1·62	·317	·82	1·77	·385
1	2	·137	4	·544	·647	2·56	1·65	·302	·647	2·21	·383
1	3	·0910	6	·544	·570	3·00	1·71	·291	·570	2·57	·374
1	4	·0685	8	·544	·525	3·38	1·77	·281	·525	2·875	·364
1	5	·0548	10	·544	·494	3·72	1·84	·271	·494	3·155	·352

In fig. 89 are shown equivalent windings with conductors of rectangular cross section. The saving has been taken advantage of in decreasing the depth of slot. The space factors are 18 per cent. higher than before, as shown in Table XLI. and by the upper curve of fig. 90. Such a winding would be considerably more expensive in labour, and there is often but little gained by making the slots shallower, but the advantage could be employed in increased output, the slot depth remaining the same, and the example emphasises the important conclusion that the use of rectangular conductors may be accompanied by considerably higher space factors, and hence, in general, is a legitimate means for obtaining a high output from a given outlay for material. The amount of the gain is a vari-

able, depending upon the required cross section and upon the ratio of the two dimensions of the rectangular conductor, this ratio being often determined by considerations of what it is

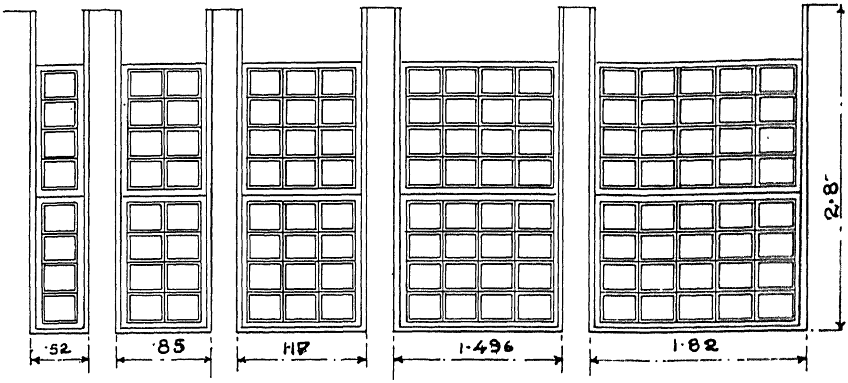


FIG. 89.—Various Arrangements of Equivalent Windings (Rectangular Wire).

practicable to wind. It may, in general, be said that conductors of square cross section, while leading to the highest space factors, are to be avoided on account of difficulties in winding. The

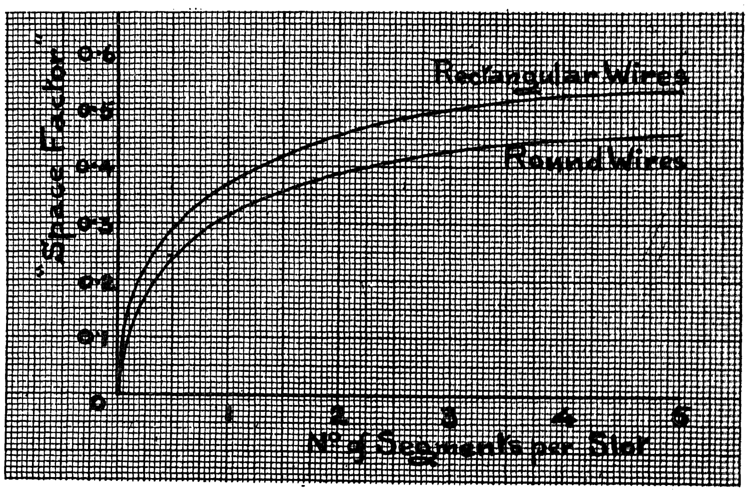


FIG. 90.—Comparison of Space Factors with Round Wires and Rectangular Wires.

ratio of the two dimensions should preferably be at least 1·5, and this materially detracts from the advantages to be derived from the use of rectangular conductors, so far, at least, as relates to

increased space factor. Even with conductors of this proportion a very considerable gain is, however, secured.

In fig. 91 are shown, for purposes of illustration, two slots, con-

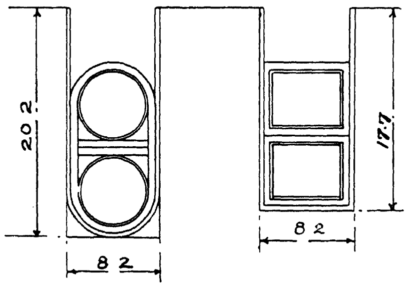


FIG. 91.—Comparison of Slots with Round and Rectangular Wires.

taining, first, two No. 4 S.W.G. (bare diameter 5·9 mm.) conductors per slot, and then two conductors of equivalent rectangular cross section per slot. It should be noted that the left-hand slots of figs. 88 and 89 (*i.e.* those with but one commutator segment

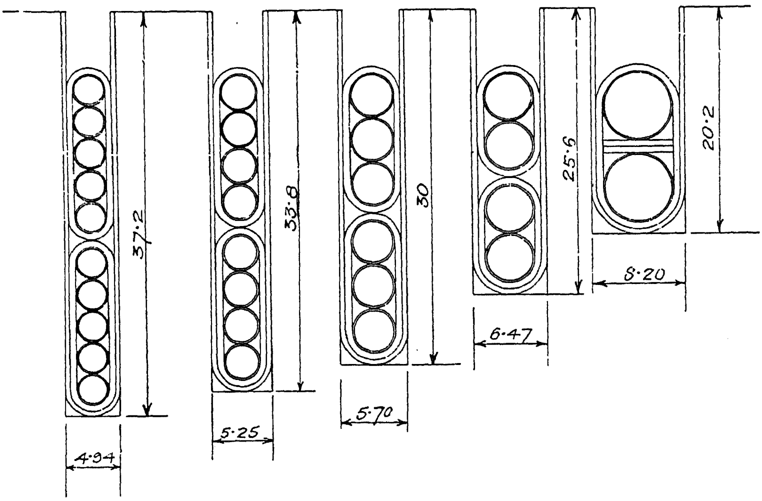


FIG. 92.—Comparison of Slots with Round Wires of a given Total Section, but with various Numbers of Wires.

per slot) have the same total cross section of copper per slot as the slots of fig. 91. Adding slots with the same equivalent copper cross section, but subdivided into 5, 3, and 2 turns per coil, we obtain the group of slots shown in figs. 92 and 93, from which

Table XLII. and fig. 94, showing the resulting "space factor," have been derived.

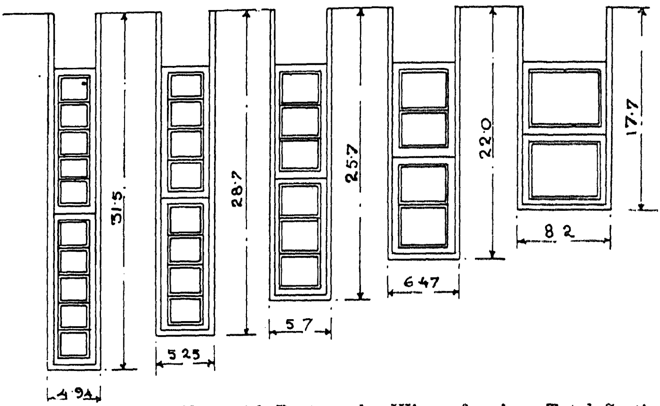


FIG. 93.—Comparison of Slots with Rectangular Wires of a given Total Section, but with various Numbers of Wires.

From the examples in figs. 88 to 93 we see how vitally the

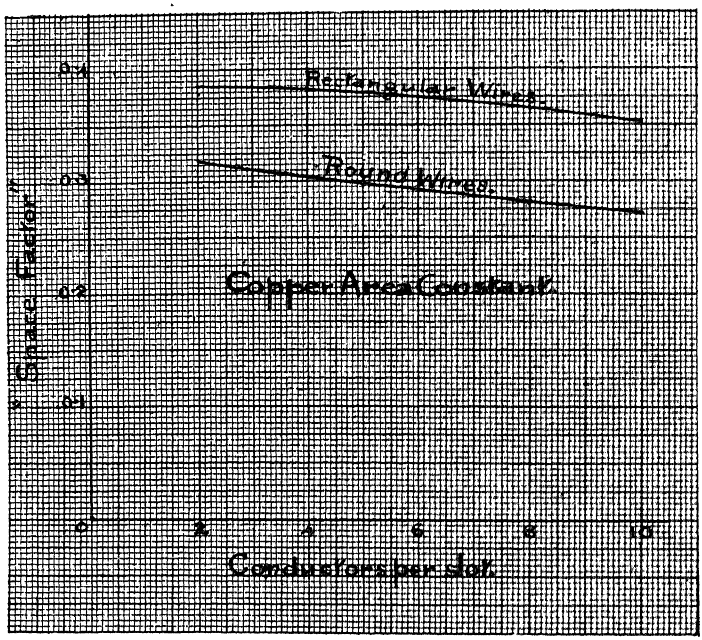


FIG. 94.—Comparison of Space Factors of the Slots of Figs. 92 and 93.

arrangement of conductors and their dimensions affect the value of the space factor obtained; and when we recollect that these

all relate to a small range of variations, no surprise will be occasioned by the statement that, in practice, armature space factors range from much less than 0·1 up to over 0·7, according to the rated capacity, voltage, and speed of the design. It is difficult to define the lines of design leading to the highest space factor. This is a matter for careful examination and arrangement in each case. Nevertheless, certain general statements may serve as useful guides:—

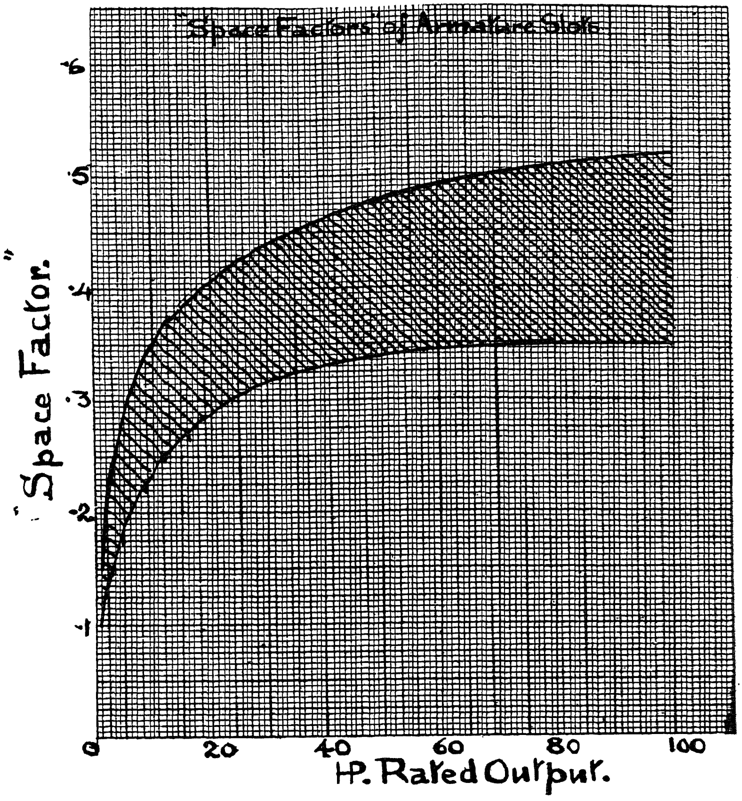


FIG. 95.—Space Factors of Armature Slots.

The space factor will generally be higher the lower the voltage, the higher the output, the higher the speed, the less the number of slots into which the winding is subdivided, and the greater the skill and the knowledge employed in the processes of winding and insulating, and in the selection and testing of insulating materials.

The shade area included between the two curves of fig. 95, is

the locus of the space factors of the armature slots of motors of from 1 to 100 h.p. capacity, designed for medium speeds and in the light of present knowledge.

For 600-volt motors, the values approach the upper limit of the shaded area, and for 100-volt motors the lower limit. Such

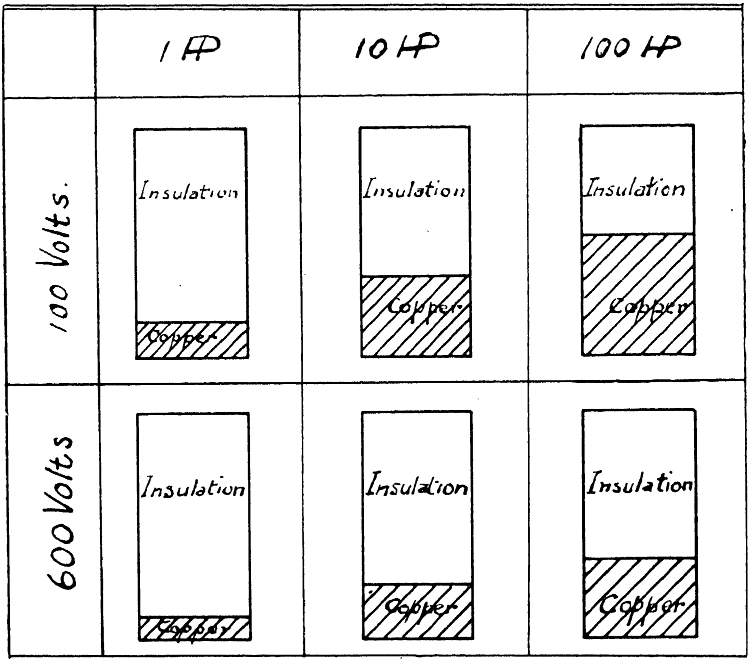


FIG. 96.—Space occupied in Armature Slots by Insulation and Copper respectively.

"space factors" are, with careful attention to details of insulating, consistent with the application of the following insulation tests to the completed armatures:—

Rated Voltage.	Guaranteed Insulation Test from Copper to Iron at 60° Cent. for 1 minute.
100	2000 R.M.S. volts.
600	3600 „

Corresponding to such motors, the shaded portions of the six rectangles of fig. 96[1] show the proportions of the total slot area

[1] Figs. 95 and 96 are taken from *Traction and Transmission*, vol. v. pp. 104–105.

occupied by copper and insulation respectively. The proportions do not reflect creditably upon the state of present knowledge of

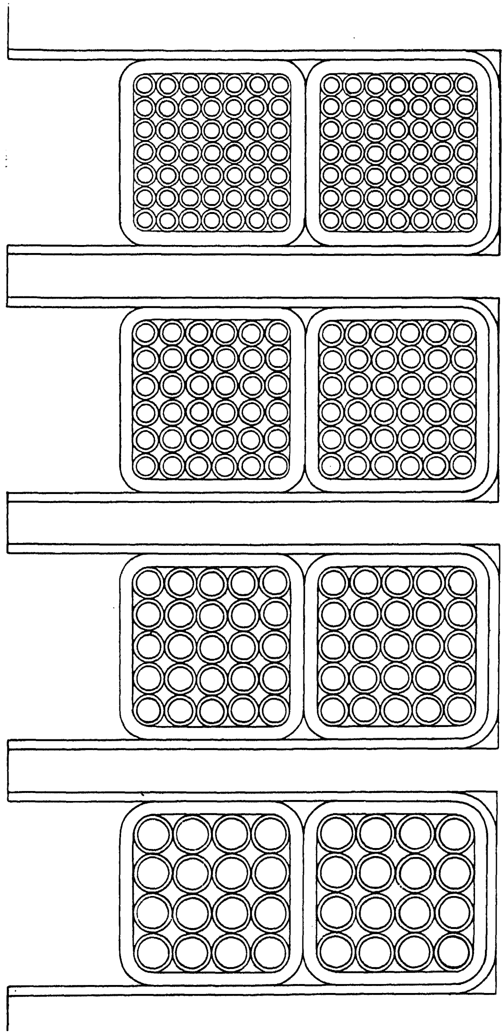


FIG. 97.—Slot Designs with Wires of various Cross-Sections and a given Thickness of Covering.

the subject.[1] If, for instance, as is evident from the lower left-

[1] "That insulators of any description should have a high insulation per mil. of thickness is a very important matter, especially in generators and motors, when looked at from the 'space factor' point of view. It is surprising what a large percentage of the available winding space is taken up by insulation in generators and motors, more especially in high-tension alternating-current work."—"On Insulation," *The Elec. Engr.* for September 16, 1904, p. 412.

hand rectangle, we could reduce the amount of space required for insulation in the proportion of 4 : 3, we could either enormously increase the thermal limit of output of the motor in question, or correspondingly greatly improve its efficiency. This is an example of one of the numerous cases where the use of silk-covered wire is the only rational and economical practice, benefiting both manufacturer and customer.

For two main considerations enter. First, the space devoted to slot lining and the "coil" insulation. This space is decreased

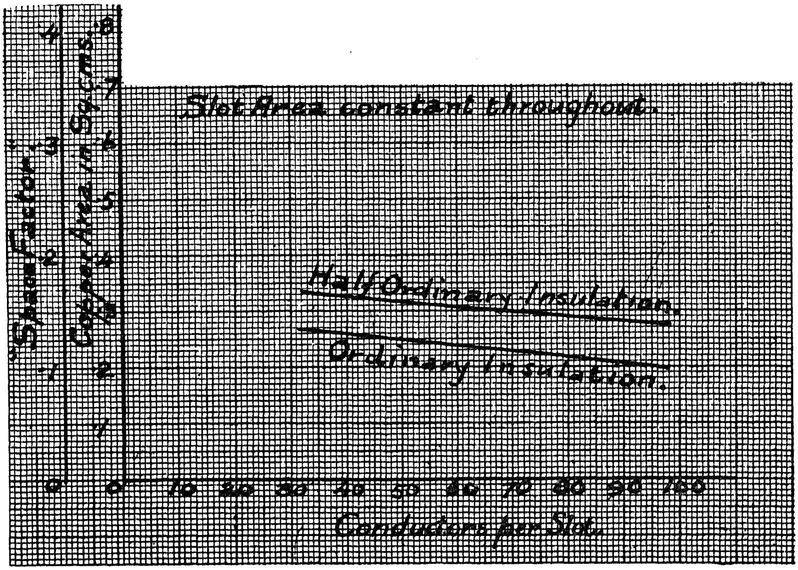


FIG. 98.—Comparison of the Space Factors of the Slots in Figs. 97 and 99.

by concentrating the conductors in few slots. Secondly, the space occupied by the insulating covering on each conductor. This latter leads to rapidly increasing percentages of lost space, the smaller the motor for a given voltage.

In fig. 92 we showed slot arrangements for a given total cross section of copper per slot: there were respectively 5, 4, 3, 2, and 1 turns per segment. Dealing with much finer wire, we may illustrate the case by the four slots shown in fig. 97. Here we have respectively 32, 50, 72, and 98 conductors per slot, arranged 4×8, 5×10, 6×12, and 7×14. The dimensions of the slot, the slot lining insulation, the coil insulation, and the insulation thickness

on each conductor conform to our original assumption, and the total copper cross section per slot falls off, as shown in the lower curve of fig. 98.

In fig. 99 the thickness of insulation in each conductor is

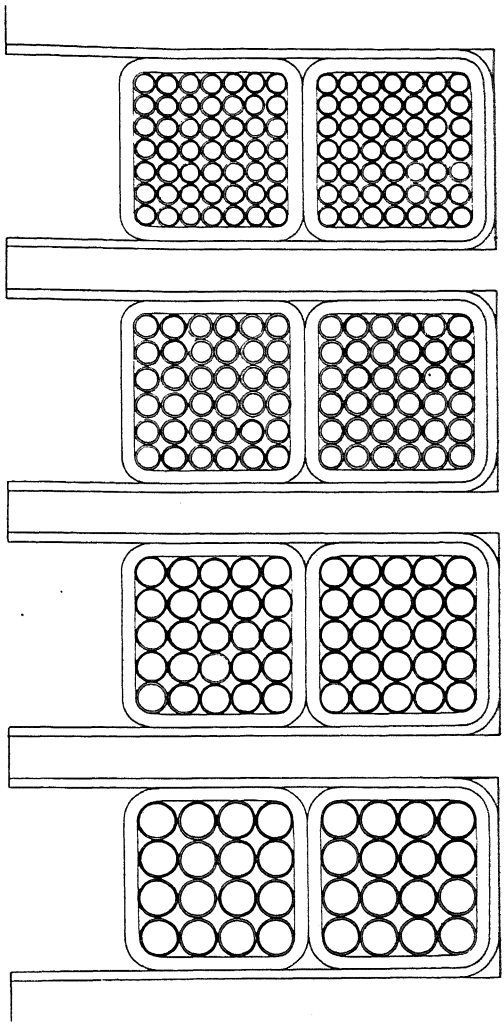


FIG. 99.—Slot Designs with Wires of various Cross-Sections and a Reduced Thickness of Covering.

halved, the other insulations remaining unchanged, and the space gained is employed by increasing the cross section of the copper conductors. The respective space factors then become as shown in the upper curve of fig. 98 and in Table XLIII. The improvement is not so obvious from a comparison of figs. 97 and 99, but is very

marked in the curves of fig. 98 and in Table XLIII., showing an average gain of 33 per cent. in the amount of copper, and hence in the space factor.

TABLE XLIII.—"SPACE FACTORS" FOR THE SLOTS OF FIGS. 97 AND 99.

Fig. 97.					Fig. 99.			
Number of Conductors per Slot.	Diameter of Conductors. Mm.	Cross Section of one Conductor. Sq. cms.	Total Area of Conductors per Slot.	"Space Factor" Ordinary Insulation (fig. 97).	Diameter of Conductors. Mm.	Cross Section of one Conductor. Sq. cms.	Total Area of Conductors per Slot.	"Space Factor" Half Ordinary Insulation (fig. 99).
32	1·47	·0147	·544	·273	1·62	·0206	·65	·332
50	1·114	·010	·50	·251	1·264	·0125	·625	·314
72	·88	·0062	·448	·225	1·03	·0083	·60	·30
98	·71	·0040	·39	·196	·86	·0051	·57	·276

Now, silk coverings may in practice be obtained of less than 75 per cent. of the thickness of cotton coverings, and a double covering affords ample security against break-downs, due to the small voltage between adjacent wires.

Suitably impregnated single-silk coverings are also practicable, and permit of still further improvement.

A compromise arrangement sometimes employed consists in the use of wires covered with one layer of silk and one layer of cotton.

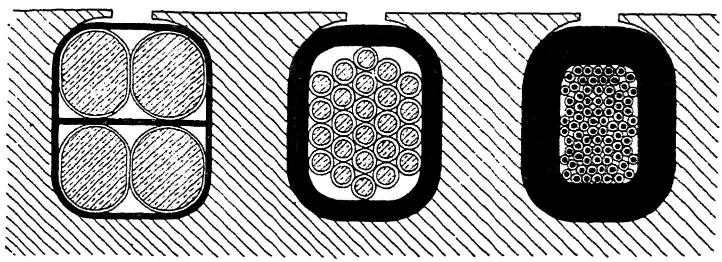
Space Factors in the Armature Slots of High-Voltage Machines.—Up to this point the space factors of the armature slots of machines for not over 600 volts have been considered. The case is very different with the high voltages often employed in alternating-current armatures. For such work the slot lining has to be much thicker, and the space factor often becomes very

low. Herr Kando[1] gives (Table XLIV.) for the case of three machines for 500, 3000, and 10,000 volts respectively, the following values for the slots shown in fig. 100:—

TABLE XLIV.—DEPENDENCE OF SPACE FACTOR UPON THE VOLTAGE.

Voltage.	Thickness of Slot Lining (mm.).	No. of Conductors per Slot.	Space Factor.
500	1	4	0·63
3,000	4	24	0·25
10,000	6	80	0·06

The question of the space factors of high-voltage alternator slots could profitably be quantitatively discussed on lines corresponding



500 Volts. 3,000 Volts. 10,000 Volts.

FIG. 100.—Kando's Illustration of the Effect of increasing Normal Voltage on the Space Factor of the Armature Slot.

to those set forth in this chapter for low-voltage slots. Herr Kando's figures, however, suffice to give a general idea of the order of the magnitudes dealt with, and it is evident that no expense should be spared in employing the very best material. This becomes the more imperative the higher the voltage.

Space Factors of Field Spools.—For field spools, the space factors are also often far lower than is generally realised. As the winding space, is to be taken the product of overall depth by overall length of the completed spool, for spools of rectangular cross section. Such a spool is shown in fig. 101. Where the cross section is as shown in fig. 102, the mean length is multiplied

[1] See Dr Thompson's *Design of Dynamos*, p. 47.

by the depth in obtaining the winding space. If flanges are employed, the length between flanges is multiplied by the depth of the winding over insulation. Such a coil wound within flanges is shown in fig. 102A.

The space factor of a field spool will be higher the lower the volts per spool; hence, for a given output, speed and voltage, the

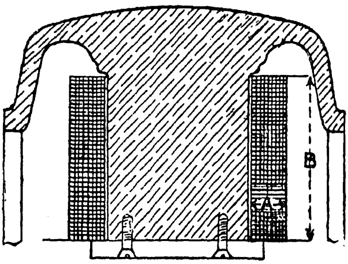


FIG. 101.

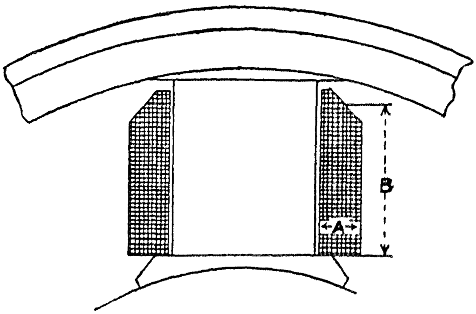


FIG. 102.

Types of Field Spool Winding without Flanges.

greater the number of poles, the higher will be the space factor, for there will be fewer volts per spool. For shunt coils, the space factors range from 0·2 in 600-volt high-speed motors for 1 to 3 h.p., up to 0·65 in large slow-speed low-voltage generators. Evidently, when the magnitude of the space factor is of the nature of 0·2 to 0·3, it is well in a given case to weigh the advantages of

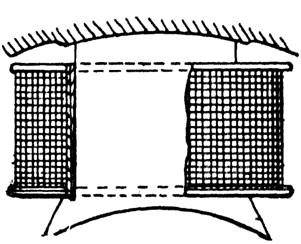


FIG. 102A.—Type of Field Spool Winding with Flanges.

silk-covered wire. In the fields of series wound motors, and in the series field coils of generators, the space factors are higher. The use of flat strip wound on edge, generally conduces to a high space factor when the cross section required is such as to permit of the choice of a strip of favourable dimensions. Space factors of 0·7 and more may sometimes be obtained in large, low-voltage, slow-speed machines, with series field spools of edge-wound copper strip.

CHAPTER XVI

THE INSULATION OF FIELD SPOOLS

QUESTIONS relating to the best methods of insulating field spools and to their general construction, constitute a subject of much interest, and one in which wide differences of opinion are held. The old method of supporting and protecting the windings by flanges constructed from castings of brass, iron, or other material, has not been entirely superseded. On large dynamos and on many of the present types of motors for heavier electric railway work they are still generally employed. This is, however, more for stiffening, and, in general, for mechanical support, than for protection. In such cases it is often quite necessary on account of the severe strains to which this class of apparatus is subjected, but for most stationary motors and for generators of only moderate size there would appear no sufficient reason for adopting such methods, as the mechanical strains do not form nearly so important a factor. In small motors, the so-called "mummified" form is at present very generally adopted below those sizes where mechanical strength renders necessary flanges either of metal or of wood. But in the "mummifying" method, the heat-dissipating capacity is largely reduced, resulting in considerably increased outlay for field copper, due to the reduced specific current-carrying capacity. In field spools with metallic cores, the insulations are only thoroughly dried out with difficulty after the wire is wound, and a vacuum drying process thus becomes almost indispensable. A shell of some insulating composition, in which the wires are wound dry, is in some respects an improvement, but is not very generally adopted. A "mummified" field spool is shown in fig. 103.

Ventilated Field Spools.—Field spools must generally be constructed to be able to withstand temperatures approaching the limits which would be detrimental to the cotton coverings. It is difficult to provide sufficient ventilation by the ordinary constructions, and hence it is important to devise means by which the ventilation may be more effective.

A ventilated field spool may be constructed with wooden end flanges, laced to the spool by means of cord carried through the winding layers, which are separated at these points by blocks of wood or other fibrous material, leaving air gaps running laterally through the windings. The increased length of wire due to these

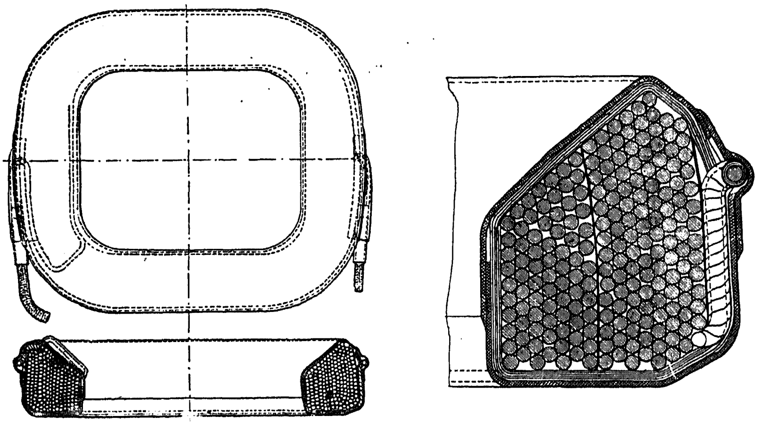


FIG. 103.—"Mummified" Field Spool.

separating blocks is more than compensated for by the greater opportunity for radiation thus provided. Of course, in such constructions, the electrical efficiency of the machine is sacrificed to a more or less considerable extent. This type of field spool construction, together with the winding form, is illustrated in fig. 104. The cylindrical surface of the wooden winding form is first covered with cord laid lengthwise, the ends being temporarily secured to the flanges. The copper wire is then wound over these cords on the cylinder, and as the winding proceeds, the cord is interlaced between the various layers, the cord serving the double purpose of providing air channels between the layers and of binding everything firmly together. The finishing layer of wire securely binds the ends of the cord.

To protect this last layer from mechanical injuries a final layer of cord may be wound over it. The spool is then removed from its winding form, baked, and afterwards immersed in a vat of suitable insulating varnish and dried. It will be seen that although the completed spool is well protected mechanically, there is liberal provision for the emission of heat through the

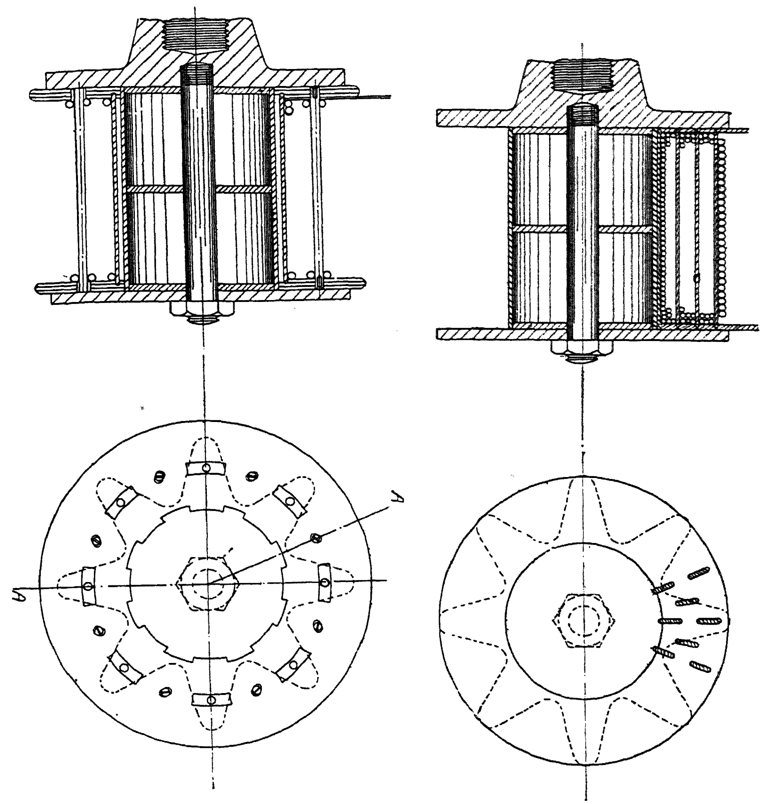


FIG. 104.—Turner's Ventilated Field Spool Construction.

channels provided by the separating cord. The impregnating varnish prevents harm from exposure to moisture or dust.

Single-cotton-covered wires generally suffice for the shunt spool windings of machines with six or more poles, and for not over 600 volts. An exception must be made for railway motors, which are generally series wound, and being completely enclosed, have reduced heat-dissipating capacity. In such motors it is

customary to use asbestos next to the copper, with an outer covering of cotton. In some cases double asbestos and double cotton covering have been and still are used, thus providing four coverings altogether. This appears excessive, as similar types of motor have been successfully built with but one layer of asbestos and one of cotton, and in still another instance with but a single layer of cotton, which was impregnated with liquid asbestos. This well illustrates the diversity of individual opinions and methods.

In recent years much attention has been given to the possibilities of increased heat dissipation by ventilation, and the tendency is toward what may be termed "skeletonised" constructions, as distinguished from "mummified" constructions. As the name "skeletonised" implies, the tapes and bands are largely replaced by cords, allowing the heat to escape between the interstices of cord, instead of confining it by the wrappings of band insulations.

Heat-dissipating impregnating varnishes of the class described in Chapter IX. are useful in the manufacture of field spools.

The possibility of thus reducing the necessary weight of copper, in virtue of these heat-dissipating methods, has been taken advantage of, and small motors, whose design limited the winding space, to the detriment of cool running, are said to have been rendered thoroughly commercial by the use of such varnishes. The spool is wound while the varnish is in a moist state, and the available space is just as compactly and effectively utilised as with untreated wires, and the completed spool, when thoroughly dried out, is cemented into a compact solid mass, which does not soften with heat, and is also moisture and acid proof.

It will thus be seen that all the advantages of the "mummified" process, such as the absence of metallic and insulating core bodies, protection against mechanical injuries, and shape preservation, may often be retained by substituting string or cord for tapes and band webbings. The heat-dissipating property of heat-conducting varnishes is assisted by the improved ventilation due to the interstices provided by the use of cords.

The enclosed magnet cores may, when deemed advisable, be wrapped with some tough, varnish-treated, fibrous material

before the completed spools are slipped in place, but this is disadvantageous from the thermal standpoint.

The cord can be, and in many cases is, dispensed with in the case of very small motors, the cementing properties of the varnish sufficing to hold the coil in shape until it is assembled in place on the machine. The pole pieces and flanges are in this case separately insulated with fibrous material, everything being finally clamped in place by the pole shoe flanges.

For compound-wound spools, the series winding may consist of copper strips wound on edge, the winding generally being in but one layer. Paper collars are employed to insulate the turns, although it would appear that some hard enamel might be employed to advantage, the layer of enamel being reinforced by strewing sand or powdered glass, or some similar insulating substance, on the surface while the enamel is still soft. When dried out, the particles would remain fixed, and allow the copper spirals to be firmly pressed together without danger of metallic contact. The tendency of the copper to thicken on its inside edges by the bending process has been compensated by some firms by employing copper drawn thinner on one edge, but this is only necessary in exceptional cases. Insulated flat copper wires can also be wound on edge, and for transformer work this is often done to great advantage, rendering it possible to arrange the wires in one layer instead of in two or more, and by the use of enamel varnish, to cement the whole spool into a transportable cylinder.

In fig. 104A (Plate 3) is shown a field spool of edge-wound flat copper strip, during the process of insulating.

CHAPTER XVII

TRANSFORMER INSULATION

CLOSELY corresponding to the mummifying methods of insulating field spools, are the methods pursued in the transformer constructions of some manufacturers. These have, however, in some cases already been superseded, as in the case of field spool windings, by the use of "skeletonised" constructions and heat-dissipating, impregnating, and cementing varnishes. This is a great improvement on the earlier methods, in which the wires were so wrapped up as to impede the emission of heat. With the same number of turns and cross section per turn, the flat conductors of the secondary may sometimes be wound on edge, and by the use of inter-braided tape, and of suitable cementing varnishes, the coil may be made to constitute a rigid cylinder, which may be slipped off from the winding form and upon the iron core of the transformer, the core being insulated by strips of fibrous materials separating the winding from the iron, and leaving air spaces, which serve as channels for the air or oil contained within the case. A cylinder of micanite slipped on over this secondary winding, and more fibrous strips arranged lengthwise upon the core, insulate the primary from the secondary, and provide air or oil channels between the winding and the cylinder. It is a good plan to separate the primary into small coils, with intermediate insulating collars between each section of winding. Wrapping should be discarded as far as practicable, in the interests of obtaining good surface radiation. Distance strips should be so employed as to prevent great depths of unventilated winding. The improvements rendered possible by these methods have been very marked, especially with respect to reduction of temperature rise.

The employment of oil in closed transformers is of great advantage, not only on account of the reduction of temperature effected by the circulation of the oil, but also on account of the preservative effect on suitably chosen insulations when immersed in oil of the right quality. The oil protects the insulation from oxidation, and thus maintains it in a soft, pliable condition. For such purposes a mineral oil must be employed, as with vegetable oils a considerable deposit of carbon soon results from the heating of the transformer. The best results have been obtained by the use of a heavy mineral oil, which although very viscous when cold, becomes thin under the influence of a moderate warmth, and flowing through the circulating channels of the transformer, leads to a very much lower temperature rise than would otherwise be obtained. The oil must have a high flashing point, must be free from moisture and all traces of acid and alkali, must not decompose nor evaporate at moderate temperatures, must be of suitable specific gravity and viscosity, and must have high insulating properties. It may be that such a long list of requirements has acted to deter some manufacturers from employing it, but the advantages gained far offset any slight expense required in subjecting the oil to the necessary tests to ensure its fulfilling the specification. Nearly one million gallons of transformer oil are now annually supplied in America, and no ambiguity longer exists as to the quality required.[1]

Nor should oil be grudgingly employed. Present practice gives the average for all sizes as about two gallons per kilowatt, but a greater amount could well be used, and with a more than compensating decrease in the outlay for copper and sheet iron. The temperature rise of an oil transformer is largely a function of the external surface of the containing case. So long as the case has sufficient surface it is quite practicable to economise in copper and iron, and the greater amount of surrounding oil will, with

[1] "Oil is a better heat-conducting medium than air, and a transformer will show a much lower temperature with oil than without. The use of oil preserves the insulation, keeping it soft and pliable, and prevents oxidation by air; consequently, the use of oil is advantageous in producing proper conditions to maintain uniform core loss and a superior insulation. The oil must be refined with special care to secure good insulating qualities and high flashing point."—Bulletin No. 9106 of the General Electric Co. (U.S.A.).

suitable design, by its natural circulation maintain the windings at as low a temperature as could have been obtained by the use of a greater weight of iron and copper, and a less liberal supply of oil.

It may be said with general truth that in all countries the transformer goes through a stage of being regarded as an unimportant detail, on which as little expense as possible should be incurred. In America alone does it appear to have completely emerged from this stage. Mr C. F. Scott, Past President of the American Institute of Electrical Engineers, recently stated[1] :—

"The one fundamental thing which underlies the adoption of the alternating current and the development of modern electrical transmission is the transformer. . . . There is a vast difference between the simple elementary form of transformer and the modern power transformer designed to transform hundreds or thousands of kilowatts at high voltages. Problems in the arrangement of the windings into a considerable number of coils, the problem of removing the heat generated throughout a large mass of material without undue elevation of the temperature, problems of mechanically supporting heavy windings which are subjected to mechanical forces tending to produce vibration or distortion of the coils, as well as the problem of insulating the transformer to withstand the very high voltages which are normal to the service and those which may accidentally appear, due to lightning or other causes—all these things have brought into transformer design and construction many elements of both theoretical and practical difficulty."

A large number of transformers in single units of from 1000 kw. to 2500 kw. each are now in regular service, whereas ten years ago transformers of as much as one-tenth of these capacities were exceptional. Over half a million kilowatts of transformers are now annually installed, and the rated output of the transformers annually installed is at least doubled every three years. The total capacity of the transformers at present in service may be estimated at over two million kilowatts, as against one-tenth this value some six years ago. Many large transformers are now in operation at over 50,000 volts. Such a transformer is submerged

[1] *Cassier's Magazine*, June 1904, p. 122, "Long-Distance Power Transmission."

in oil in an iron case, and coils of brass tubing, also immersed in the oil, surround the transformer at its upper end. Water is circulated through these coils, and maintains the oil and the transformers at the required low temperature. A 2000 kw. transformer of this construction requires only about 5 gallons of water per minute, or 0·15 gallon per kilowatt rated capacity per hour. In sizes up to 500 kw. the water circulation is unnecessary, sufficient cooling being secured by the natural circulation of the oil. In an article in *Cassier's Magazine*[1] by J. S. Peck it is stated that—

"In the transformer, the function of oil is to insulate and to cool. As an insulator, oil has strength several times that of air, and is of particular value for the insulation of exposed surfaces which in air, under very high-voltage strains, act as conductors. The fluidity of the oil also gives it an advantage over solid insulating material, in that it is self-healing and offers the same insulation strength after a discharge as before. It is also of value for sealing in cracks or openings which may be left in the solid insulating material. As a cooling medium, oil acts as a conveyor of heat rather than as a conductor. Coming into contact with the active parts of the transformer, it is heated, rises to the top, flows over the sides, and coming in contact with the cooling surfaces, sinks, and rises again past the heated surfaces. Thus a rapid circulation is automatically established, and the heat is conveyed from the active parts of the transformer to the surfaces provided for its dissipation. The specific heat of oil per given volume is very great as compared with air, and on account of the great fluidity of oil it will pass through comparatively small ducts."

In the May number of the *Electric Club Journal*, of Pittsburg, U.S.A., it is stated by Mr C. E. Skinner that—

"At the present time the use of oil for the higher voltage transformers is considered absolutely essential, and a very large proportion of the low-voltage transformers of large size are also oil-insulated The use of oil for small house-to-house transformers is now almost universal practice in this country. . . . By transformer oil is meant an oil in which the transformer is completely immersed, forming a homogeneous insulation for

[1] June 1904, p. 137, "Transformers for Long-Distance Power Transmission."

those parts of the transformer which are not otherwise insulated, and also adding to the insulation of such materials as may be permeated by the oil, such as the cotton covering of the wire used. The transformer oil also forms a cooling medium, whose function is to receive the heat from the coils and core, where it is generated, and carry it to the outer and cooler parts of the transformer. Owing to the fact that the oil expands when heated, the hot oil rises, and the colder oil from the sides of the containing tank flows in to take its place, thus setting up a circulation of the oil which continually cools the transformer."

The chief difficulty in the construction of transformers for immersion in oil, relates to the choice of insulating materials which will not be affected by the oil.[1] Rubber must in no case be used, as it is so quickly attacked by the oil. Hence rubber tubing, rubber bushings, rubber tape, and leading-in cables containing any rubber whatsoever, must be rigorously excluded. Oiled cotton and linen tapes are permissible, as also are presspahn and paper.[2] Indeed, it would be well if the insulation in oil transformers could be confined to paper to a far greater extent than is at present the practice.

In Skinner's National Electric Light Association paper (1904), he states that the "viscosity of transformer oil, within limits, is not of great importance, although in general the more fluid the oil, the more rapid will be the circulation of the oil in the transformer tank, and consequently the greater the cooling effect. The viscosity seems to bear no relation whatever to the insulation tests, the lighter oils—such as kerosene—showing as high or higher insulation tests than the very heavy oils. Tests for viscosity require special apparatus and special care in testing, and such tests are not usually considered necessary in connection with transformer oil. The oil is always in a fluid state when the transformer is in operation, and no harm whatever would result from the oil congealing in the transformer, inasmuch as there are no moving parts.

[1] "One important point for dynamo and especially transformer insulation is that the oil used should not have a dissolving or other effect on the insulating material."—Dr Max von Recklinghausen.

[2] Presspahn dried in vacuum and then kept twelve hours in transil oil at 120 degrees C. gives most excellent results.

Oil with a high cold test may not, however, be suitable for use in oil switches which may be subject to intense cold, as the switch may 'freeze up,' due to the congealed oil, and fail to operate on this account."

The following quotations are taken from the same source :—

"**Colour of Transformer Oil.**—For convenience in handling, it is desirable that a transformer oil be water-white in colour, but this is not at all necessary, and as the production of the water-white oil usually means chemical treatment, it is best to use a darker oil, rather than to risk any chance of having traces of chemicals in the oil. Most oils get darker with continued use. The quality of the oil from an insulation standpoint does not apparently suffer any change whatever due to darkening under the influence of temperature.

"**Sulphur Compounds.**—The action of sulphur on the insulation of transformer oil, while not yet thoroughly investigated, has shown, in the few tests which the author has carried out, to be very detrimental, and it is therefore considered best to eliminate sulphur compounds from transformer oil. Western oil is particularly liable to contain sulphur compounds, and therefore liable to give trouble from this cause. In some tests carried out some time ago the insulation resistance of a model transformer, after remaining at a very high value at high temperature for nearly a year, was lowered to the danger point in a few days by the introduction of a small amount of sulphur into the oil.

"**Deposit.**—In actual service, it sometimes occurs that a brownish or black deposit is formed in the oil. Careful experiments have shown that this deposit is a phenomenon of temperature alone. This deposit is formed from the oil and from the insulating materials, such as varnishes, etc., which are used on the solid insulation of the transformer. This deposit is itself a good insulator, and the only harm done by such deposit is to impede the cooling of the transformer by lodging in the ventilating spaces and on the cooling coils of a water-cooled transformer. In the very high-tension transformers there is also a tendency for this deposit, when it does occur, to line up at points where the stress is greatest. Such deposit does not necessarily mean a deterioration in the insulation of the oil, or of the transformer, and occasional cleaning

of the parts on which the deposit occurs is all that is necessary to keep the transformer in good condition. Where the transformer tops are partly open, the deposit will contain dust and dirt, which naturally get into the transformer case.

"**Action of Waterproofing Compounds.**—In many transformers, waterproofing compounds are used which may or may not be soluble in the oil in which the transformer is immersed. These waterproofing compounds are necessarily good insulators. The materials used may have either an asphalt, coal tar, or linseed oil base. When asphalt or coal tar base compounds are used, they are always somewhat soluble in oil, especially when the oil is hot. Compounds having a linseed oil base, when thoroughly dry, are practically insoluble in mineral oil. When large quantities of waterproofing material, with asphalt or coal tar as a base, are used in transformers, the compound resulting from the combination of the waterproofing material and the transformer oil may form a pasty mass, which will close up the ventilating spaces, and consequently cause dangerous heating of the transformer, due to lack of ventilation. From an insulation standpoint there is no objection to the waterproofing compound being dissolved out after the transformer is put in service, provided the design is such that the ventilating spaces which are essential to the cooling of the transformer are not filled up. Any compound which is soluble in mineral oil should not be depended on for cementing parts of the transformer, or for closing spaces when this compound may be dissolved out by the oil later. The linseed oil compounds are waterproof in the sense that they will not allow water to pass through where there is an unbroken film; but they are not waterproof in the same way that asphalt and coal tar base compounds are waterproof, *i.e.* they are not 'water-repellent.' When transformers are treated with linseed oil compounds, more care must be taken to prevent the absorption of moisture than when the other class of compounds are used."

Skinner points out that, contrary to an idea which has become somewhat widespread, the use of oil in transformers is perfectly safe from the standpoint of the fire risk, since oil as a body is the reverse of inflammable. He relates that "in carrying out some tests on a very high-tension transformer, a spark passed between

leads above the surface of the oil, igniting some fibrous material which surrounded the high-tension leads above the oil level. This fire was readily extinguished by dipping oil from the tank and pouring on the blazing part."

"In another instance, a transformer was suspended above the oil tank for the purpose of making some examination with current on. Owing to a fault, the transformer, which was thoroughly oil-soaked, was set on fire and was burning fiercely. It was dropped into the tank of oil, and the fire was extinguished immediately."

An interesting phenomenon has been observed in transformers in which the high-voltage primary coils consist of a few long layers. There was, as a result, a high voltage between adjacent turns at the ends of these long layers. In the particular case of a thirty k.w. transformer, this amounted to several hundred volts per layer. The insulation between layers consisted of a few thin sheets of red rope paper. This was ample to prevent a break-down. Nevertheless, if the core loss, measured cold, amounted to a certain amount, say 200 watts, and if then the transformer was run with load until a temperature rise of some 50° Cent. had occurred, then, on throwing off the load and re-measuring, it was found that the apparent core loss had been more than doubled. When again cold, however, the original value of the apparent core loss was again observed. Repeated tests with several transformers confirmed these observations. On reducing the voltage per layer to one-half, by subdividing each of the long primary coils into two coils of half length, the increased loss was still observed, but it was of materially decreased amount. The transformers also then ran cooler with a given load. It appears that at high temperatures an ohmic loss, due to the very small leakage current flowing through the insulation, was taking place. This is quite credible when one considers how very greatly the insulation resistance of most insulating materials decreases with increasing temperature. An instance of this has already been given in fig. 21 on page 36.

Of course the remedy in such cases consists in subdividing the single long coils into short component coils. This inevitably requires more total space for insulating material. One may of course employ thicker and better insulation between layers. Sufficiently thorough investigations would probably also show

that with different materials this effect varied sufficiently to justify great care and increased expense in selecting materials of such a nature that the insulation, while high at low temperatures, decreased least with increasing temperature.

Fessenden, in 1898, suggested that "by dissolving a solid, non-dissociating substance in the oil in such excess that it crystallises out at ordinary temperatures, and forms with the oil a soft gelatinous mass, not fluid, but yet capable of allowing the oil to ooze through its substance," one could in oil transformers make use of the property—if the substance were, say, paraffin—that the large specific heat of liquefaction would prevent an overload from raising the temperature of the oil above a fixed point, until the paraffin is all melted. He states that this method would have the disadvantage associated with the use of an oil of great viscosity, namely, that it would not re-insulate so quickly after a discharge.

Now that such exceedingly high voltages are employed in practice, the question of transformer insulation is of great importance. Two-thousand-volt transformers in America are tested at from 8000 to 10,000 volts from primary to secondary, and from primary to core and to frame. Transformers for higher voltages are required to show a but slightly lower factor of safety, and 10,000-volt transformers should withstand the application of 25,000 volts from primary to secondary and to core. It is only by a policy of conservative, sound work that electrical power transmission at over 60,000 volts has been successfully carried out. In a recent paper contributed by Moody[1] to the *Transactions of the American Institute of Electrical Engineers,* we find the following impressive paragraph:—

"Eighty thousand volts is the highest pressure that is now practicable for transmission work, but transformers and insulators must be tested, consequently there is some demand for transformers working up to 200,000 volts. The insulation of the terminals of such transformers is the most formidable part of their design. As yet, I know of no satisfactory solution of the problem, except to use oil-filled tubes as terminals. A terminal that has withstood 375,000 volts without any indication of weakness is constructed as follows:—

[1] See also p. 119.

"The tube was the shape of two truncated cones, bases together; about 12 inches in diameter at the centre, and 4 inches at either end; it was built up of thin wooden rings, telescoped a short distance into each other, and held together by the conductor, which, for mechanical purposes, was made quite heavy, and which was located in the axis of the cones and supported by washers at either end of the tube; between each section of the tube were collars of insulating material, some 3 inches larger in diameter than the tube, which served the purpose of greatly increasing the leakage surface. After the sections were drawn tightly together by nuts at each end of the conductor, the whole structure was repeatedly dipped in varnish and dried, thus sealing all joints. The terminal was mounted with the lower end several inches under the oil in the transformer, and with its largest diameter on a level with the cover; the lower end of the tube was tightly sealed, making the tube perfectly oil-tight."

In England and on the Continent the requirements for transformer insulation tests are too low. They generally consist in subjecting 2000-volt transformers to an insulation test at double the working voltage, and subjecting high-voltage transformers to test at but 50 per cent. above the normal voltage.[1]

[1] A portion of the contents of this Chapter is taken from an earlier publication by one of the authors.

CHAPTER XVIII

INSULATING ARMATURE PUNCHINGS AND LAMINATIONS IN GENERAL

PRACTICE varies widely as regards the means employed for insulating laminations from one another. In the early days thin paper was employed, but this was an expensive method as regards both material and labour. Some manufacturers even now employ ordinary shellac varnish, but this is altogether unsuitable, since not only does shellac varnish absorb moisture, but it softens at moderate temperature, and also crumbles to powder in the course of time, and the more rapidly the greater the vibration to which it is subjected. Another practice is to oxidise the surface of the plates, the oxidisation being accomplished by the use of acids and their fumes.

The most general practice nowadays is to coat the surface with a quick-drying Japan varnish. Care should be taken to select a varnish that will not soften under heat, nor crumble with heat and age.

The laminations may be passed between a pair of rollers, of which the lower one is immersed part way in the varnish, which it carries to the upper roller, and the laminations passing between them become coated on both surfaces with the varnish. After leaving the rolls, a long endless chain carries the plates over a series of hot blast pipes, so perforated that the air impinges on the surfaces to be dried. The plates are finally deposited in a suitable receptacle at the other end. An apparatus for the purpose is shown in fig. 105. The plates may be passed successively through a number of coating rollers. They should finally be powdered with French chalk, which gives an extremely fine coating of mineral insulation, increasing the efficiency, and preventing the plates

from sticking should they not be thoroughly dried when assembled in packs.

The rolls should be made of metal, and coated with printers' gum or gelatine, as rubber would deteriorate under the influence of the turpentine or benzine solvents. The surfaces must be clean and free from all oils and from metallic dust. If turpentine is used in place of soap and water or oils during the stamping process, no extra labour for cleaning will be necessary, and the varnish will stick all the better, since turpentine is allied to the solvents most generally used in practice to thin down the varnish. Of course, in cases where the punchings are annealed after leaving the stamping press, all oils and soap are removed by this process, but in some cases it is practicable to avoid re-annealing after

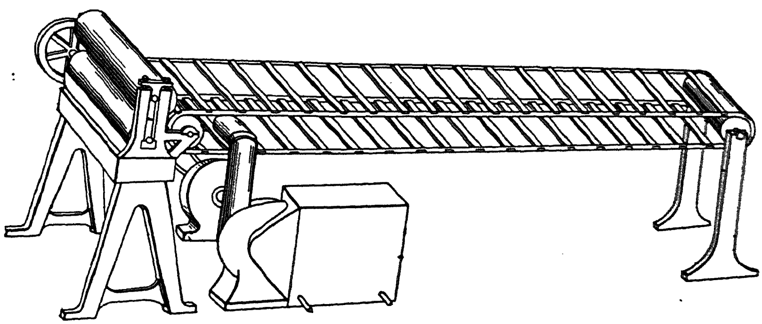


FIG. 105.—Apparatus for Varnishing Core Plates.

stamping, thus saving the expense of an annealing oven. When this is the practice, the punchings must be freed from oil before applying the varnish, otherwise the varnish will not form an even and secure coating. The drying may be hastened by first placing the punchings in a heating oven and running them through the varnishing rolls while still hot.

Core Plate Varnishes.—Gilsonite, Asphalt, and other materials of this class, form the base of some of the best varnishes for this purpose. The specific gravity should not be over 0·83. The plates may be passed successively through a number of coating rollers. The pressure with which the core plates are assembled has been found, for the range of pressures employed in practice, to affect the insulating results but slightly. A pressure of 8 kgs. per square centimetre is fairly representative of standard practice.

To study the effect of pressure, discs of 32 cms. diameter, with edges well rounded and irregularities removed, were coated on both sides by the standard method above described. Twenty discs of each variety of varnish were used, and plain discs separated each variety. These plain discs served as terminals from which measuring leads were carried to a Wheatstone bridge. This aggregation was placed under a hydraulic press and readings were taken at various pressures. The pressure applied was far greater than that employed in practice, in order to better determine the effect of pressure in reducing the electrical resistance. The results at the excessive pressures employed in these tests, showed some dependency upon the kind of insulation employed.

Micrometer gauges cannot very accurately measure the thickness of the coating, owing to the variation in the thickness of the iron, and also to the unequal distribution of the varnish. After coating with varnish, the punchings should be packed in cases in order to avoid scratching the surfaces and mechanically injuring the plates.

A series of experiments with a score of different samples, brought to light the value of celluloid lacquer such as is used in coating polished brass and similar metals. Iron laminations immersed while warm in a vat of lacquer, dry quickly, and have a thin, smooth, even highly insulating coating. Neither heat, moisture, nor acids affect the coating, which is very durable.

A coating of celluloid lacquer on the plates is so extremely thin that a gallon would coat several times as much surface as a gallon of any other liquid insulator, giving the same insulating resistance, and it spreads itself more uniformly on the surface. It will also dry at least as quickly as any other suitable varnish, so that although the cost per gallon is much greater, economy may nevertheless be obtained by its use.

Copper wires have, for a limited class of work, already been successfully insulated with collodion varnishes, and developments in this direction will probably ultimately lead to further improvements in the insulation of electric machines.

One of the materials on the market for insulating sheet-iron, is called "insuline." It is alleged by its manufacturers to possess the following advantages:—

"A good insulator effectually preventing eddy currents between the discs or sheets.

"Very thin, occupying much less room than any other insulator used for the purpose. This is especially important with very thin iron sheets, making a practical and useful addition possible in the amount of iron that can be got, for example, into a given length of armature, thus reducing magnetic density, or giving advantages in other ways.

"Unaffected by any temperature reached in practice. Does not slowly squeeze out or decompose.

"When applied to toothed armatures it covers the teeth equally with the rest of the disc.

"It is put on after stamping and annealing."

The manufacturers of armalac claim that it is suitable for coating armature core plates. They give the following directions for its use for this purpose:—

"To insulate an armature, dip laminations in armalac which has been thinned down with petroleum naphtha until it leaves a film of not over $\frac{1}{1000}$ of an inch thick. In plants where a large amount of work is handled, the laminations are painted by passing them between printers' rolls, the lower one of which runs in a trough of armalac.

"It is a waste of time to bake laminations on which armalac is used. They are completely dry in a few moments."

Graphite has also been employed for coating core plates.

CHAPTER XIX

TAPING MACHINES, AND TAPES AND BANDS

TAPES play such a large part as insulators in the electrical

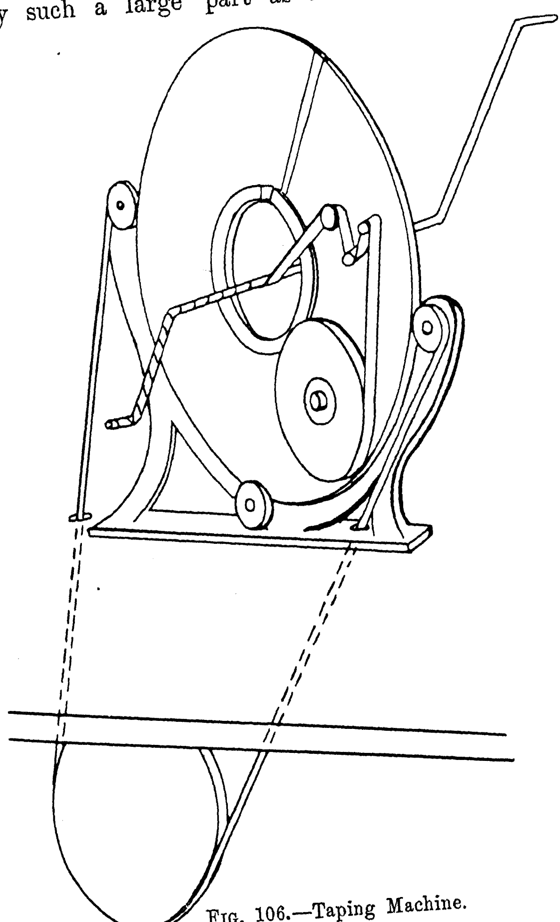


FIG. 106.—Taping Machine.

industries that mechanical means have been devised for applying the tape. Figs. 106, 107, and 108 illustrate various types of

machines by which this is accomplished. A photograph of such machines in use is given in fig. 109. A slit in a metal ring, to which the tape roll and guides are attached, admits one side of the

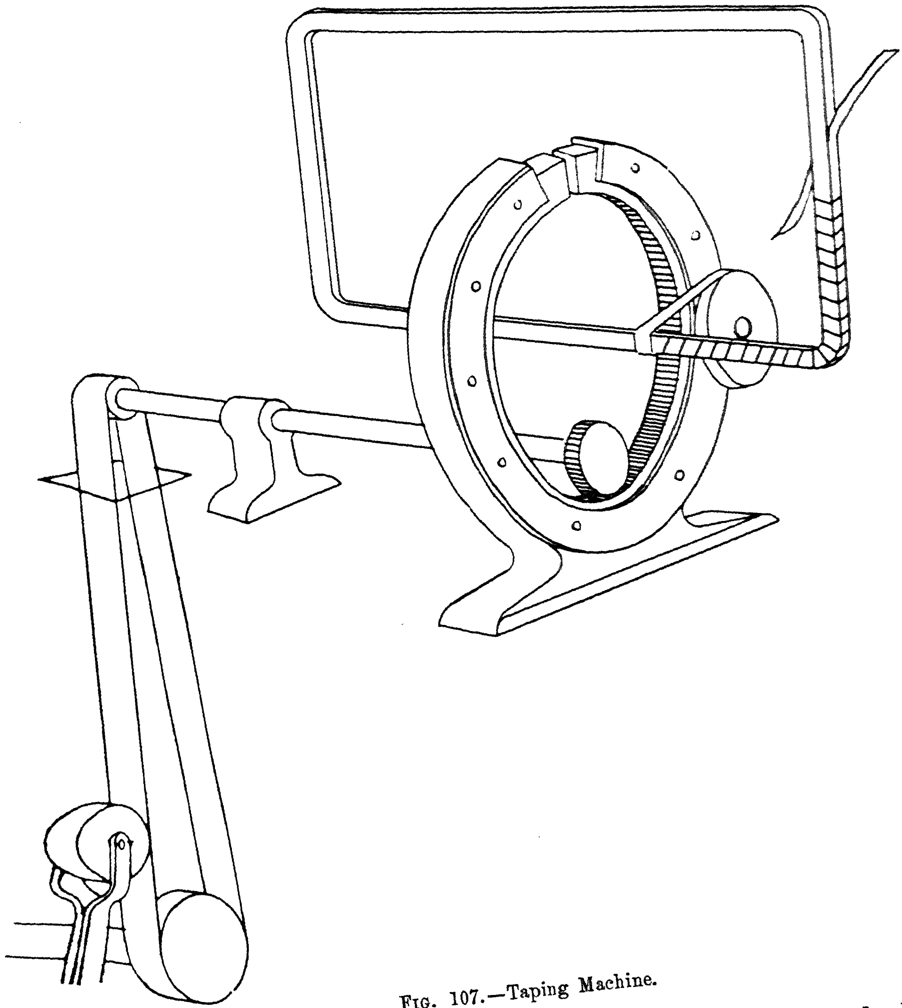


FIG. 107.—Taping Machine.

coil, to which the tape is to be applied. The ring is revolved about the conductors, which are held in the centre of the ring, and are fed through at speeds proportionate to the amount of tape overlap required. The tape roll is held in place by spring clamping discs, which are adjusted to the amount of tension necessary

for each case. A foot lever operates the friction clutch controlling the speed of the machine, thus leaving the operator's hands free for holding the work and guiding it through the machine. Where a large number of bars are to be taped, mechanical appliances are employed for supporting the bars and feeding them through the taping machine. These appliances comprise a set of clamps

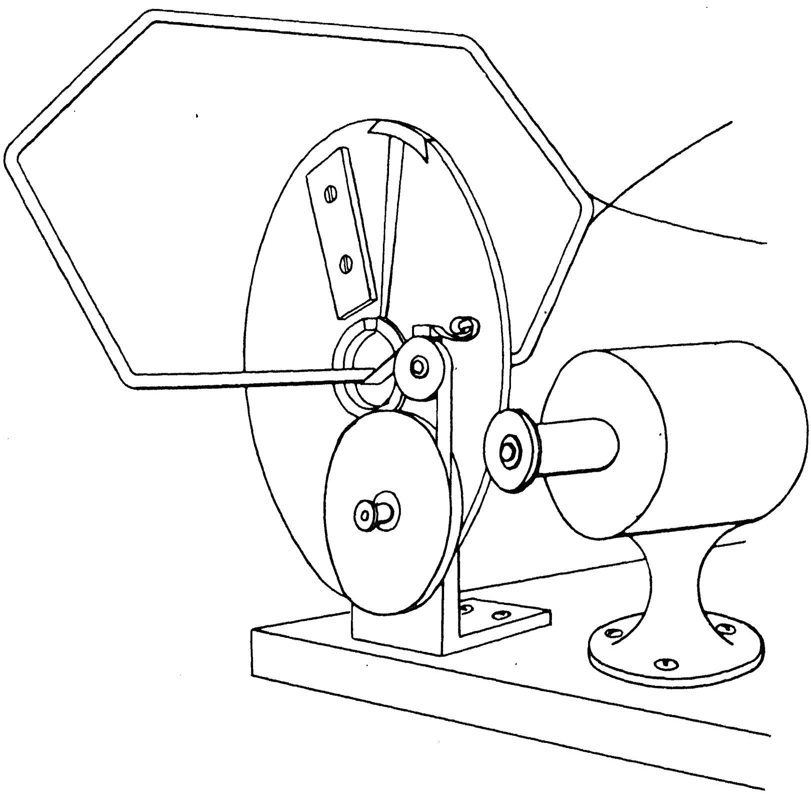


Fig. 108.—Taping Machine.

mounted on a carriage travelling in the direction of the work to be taped, at speeds adjusted to correspond to the amount of overlap required.

An improved and simplified form of taping machine, devised by one of the authors, is illustrated in fig. 110. In this design the power shaft runs immediately below the bench. A pully is keyed to this shaft; another pulley is carried on the end of an arm pivoted on the shaft's bearing. Over these two pulleys runs a

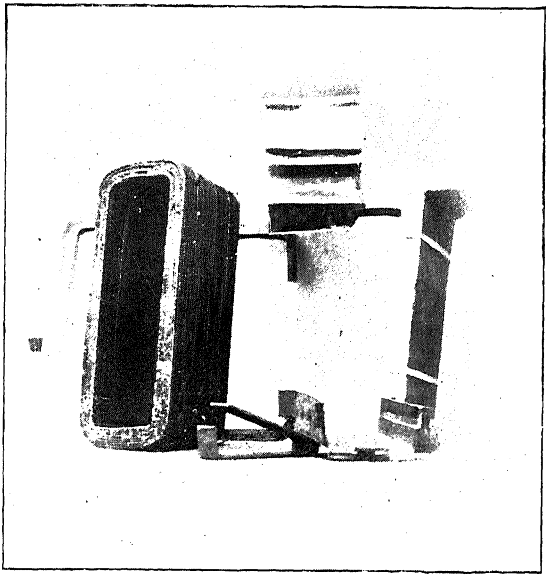


FIG. 104A.—Field Spool Insulating.

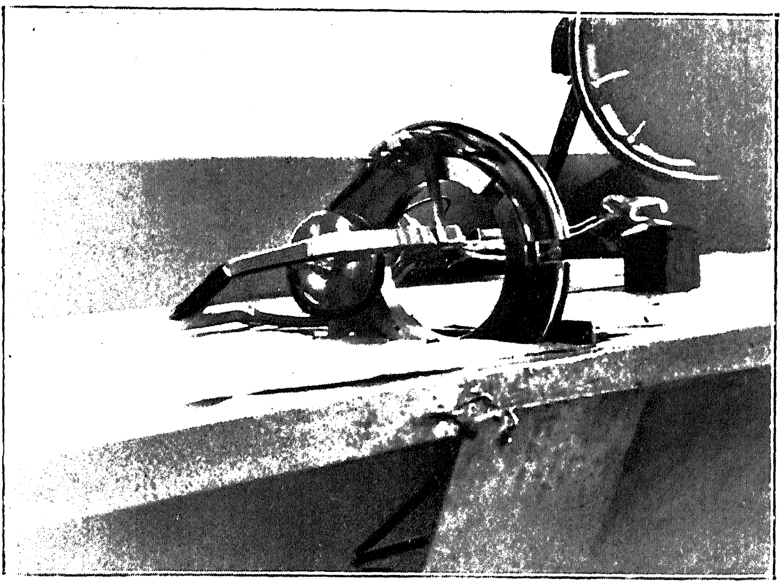


FIG. 110A.—Turner's Taping Machine.

[*To face* p. 237.

round leather belt, which may be brought to bear on the under side of the taping pulley, by operating the foot lever. In fig. 110A is given a photograph of a machine constructed on this principle.

Tapes and Bands.—At Barmen and Elberfeld in Germany are located mills manufacturing a considerable proportion of the tape employed in the electrical industry. Such tape must be strong, flexible, and free from sizing. A yellowish-tinged tape of fine texture and about 0·13 mm. thick, is most widely used. For all-round work, the most convenient width is from 16 to 18 mm.

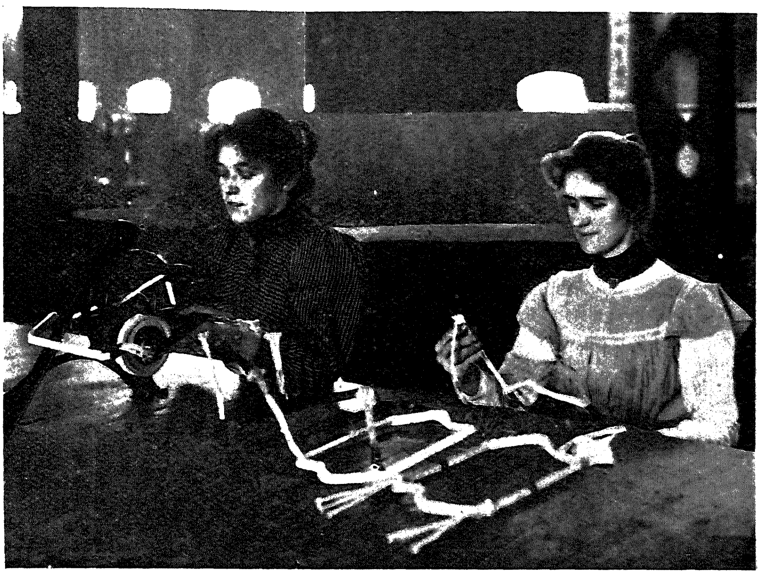


FIG. 109.—Taping Machine in Use.

As the tape is applied mechanically at fairly high speed, it is necessary to make certain that if the roll is not in one piece, the ends are joined by thread, for cases have occurred where small pins have been employed, and their presence in the roll escaping detection, the tape, with the pins, has been bound upon the coils, and the latter assembled upon the machine. Such a fault may escape detection and ultimately lead to the breakdown of the insulation.

The rolls of tape have a 10-mm. centre, and should be about 150 mm. in outside diameter, in order to be conveniently mounted in the taping machine.

"Jaconet" is the trade name by which the most widely used cotton or semi-cotton coil-insulating tapes are known. It should be remembered that tapes serve as a means for holding the impregnating varnish and for separating the conductors from one another, and it is important to secure thin tapes of a uniform and fine

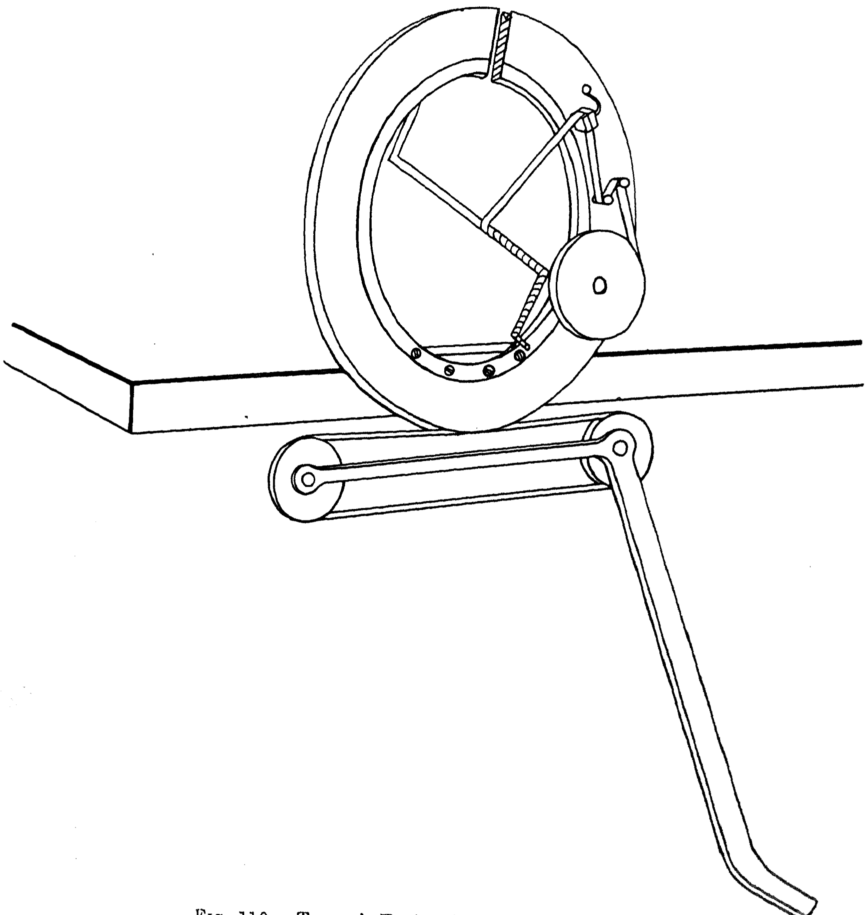


FIG. 110.—Turner's Design for Taping Machine.

texture. The adjustment of the overlap to suit the requirements of each case is a matter of considerable importance.

It has been found advantageous in large electrical works where many varieties of tape are used, and there is difficulty in stocking such tapes in requisite quantities, to manufacture the tapes from rolls of cloth, the difficulty of selvage edges being overcome by

varnishing impregnations. The method of making these tapes is to take a roll of cloth, dry it out in a vacuum oven, immerse it in a tank of insulating varnish, and then wind the cloth from this tank, direct on a mandril in a lathe, the cloth passing over straight edges to keep it smooth, and to provide a smooth, thin coat of varnish. This cloth on the mandril is then revolved at a high rate of speed, and a cutter attached to the slide rest of the lathe cuts the cloth to any width desired. It is the practice to treat this cloth and keep it on the mandrils ready for cutting as

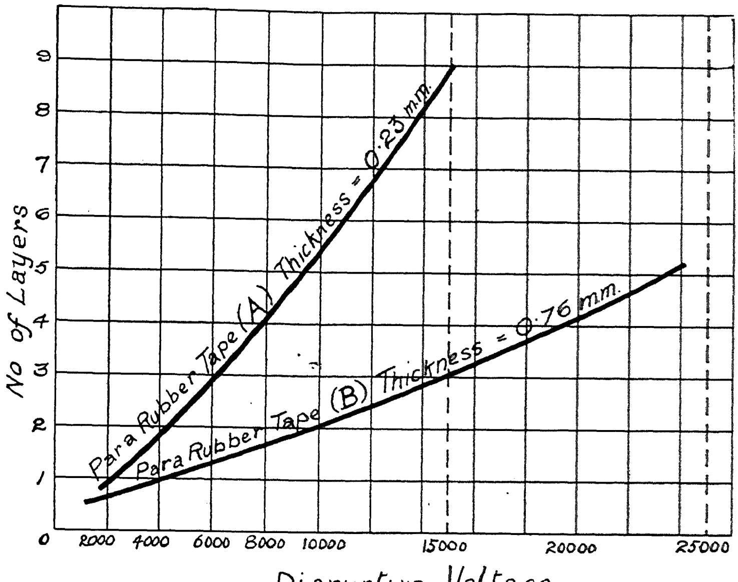


FIG. 110B.—Holitscher's Curves for Para Rubber Tape.

occasion requires, and when the tape is used on a taping machine, it will be found that the tape is more elastic and provides a more perfect insulation than is obtainable by other methods. Insulating varnishes are subsequently applied, filling up the interstices and making a thoroughly moisture-proof surface. The insulating varnish should be of a permanently plastic nature, otherwise it is liable to dry out and become brittle.

Rubber tape should never be employed in armature insulation. Excellent as it may be as an insulator when freshly applied, its rapid deterioration under the best of circumstances, and especially

under the influence of oil, prevents its employment in such machinery.

In many cases the thin rubber film is merely solutioned to the canvas. If vulcanised to the canvas it would be better, but for the fact that rubber oxidises so rapidly, and to make the tape cheap it is "gorged" with impurities to such an extent that under no conditions would it be a suitable material for armature or transformer coils.

Holitscher's results for the disruptive strength of Para rubber tape are given in the curves of fig. 110B.[1]

[1] *E.T.Z.*, February 27, 1902, p. 171.

CHAPTER XX

DRYING INSULATIONS—VACUUM DRYING OVENS

IN the earlier days of the dynamo industry, very crude methods were employed in drying-out apparatus. In many cases the drying consisted largely in heat runs of the apparatus. Even now in large apparatus a final drying is often effected in this way, and,

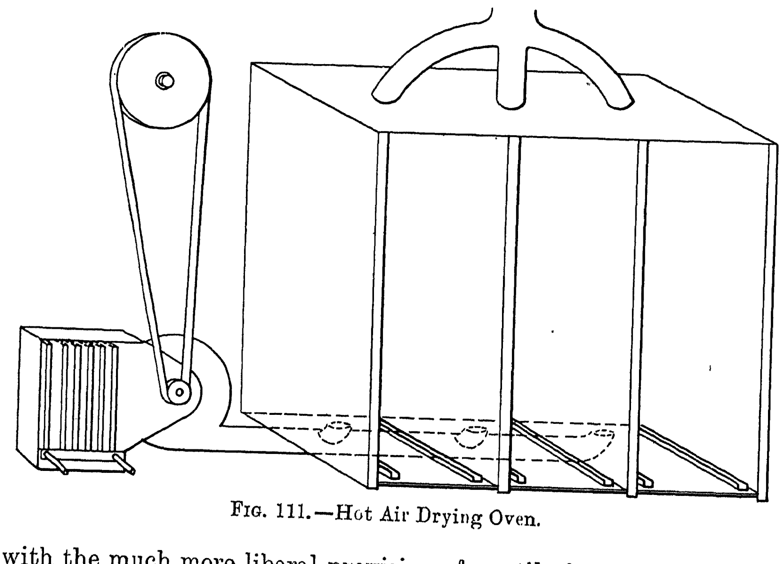


FIG. 111.—Hot Air Drying Oven.

with the much more liberal provision of ventilating ducts throughout the machine, this is far more effective than in the old days. Although expensive, it is often better to send continuous current through the windings from an external source, as there is then no voltage present except the small C R drop, and the windings need not be subjected to high potentials until well freed from the last traces of moisture. Such methods are, however, crude and

expensive. It was formerly sometimes the practice to build charcoal fires around the fields and armatures in an enclosure of sheet iron, or even of rough boards lined with sheets of asbestos, and to-day one frequently finds large armatures being dried out by surrounding them with temporary banks of steam pipes. Gas ovens are also sometimes used, but more especially for drying out commutators and mica insulations.

Some firms employ steam ovens, through which a circulation of

FIG. 112.—Bank of Hot Air Drying Ovens installed in a British Dynamo Factory.

air is maintained by fans. Others first heat the air by steam pipes in special ovens, afterwards blowing it through the ovens containing the apparatus to be dried. This type of oven is illustrated in fig. 111. A bank of hot air drying ovens installed in a British dynamo factory is shown in fig. 112.

Vacuum drying ovens are, however, now generally considered indispensable by electrical manufacturers. These ovens are of cast or wrought iron, and are lined internally with jointless steam pipes. By external valves, the temperature may be maintained at the required value (generally 60° C. to 95° C.).

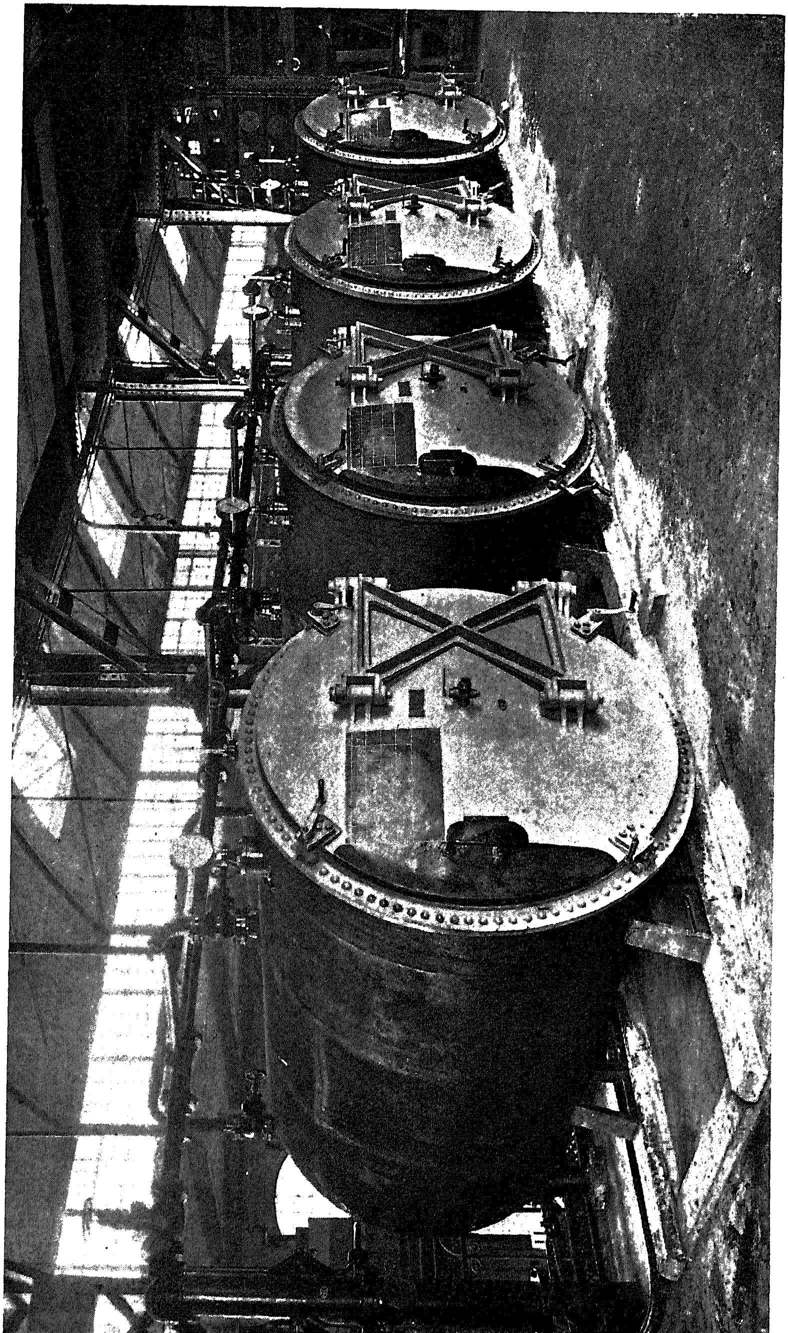


FIG. 113.—Bank of Four Vacuum Ovens in a Continental Dynamo Factory.

An air-pump exhausts the air, and with it the moisture, maintaining a vacuum of 93 per cent. (28") and upwards. As with 28" (710 mm.) of vacuum the boiling temperature of moisture is 38° C., and with 29" (735 mm.) only 25° C., it follows that an article, even when subjected to very moderate temperatures, say 30° C. or 40° C. above the boiling temperature, is certain to become thoroughly dry in a very short time. In the case of varnishes requiring oxygen for drying, air may be admitted during every

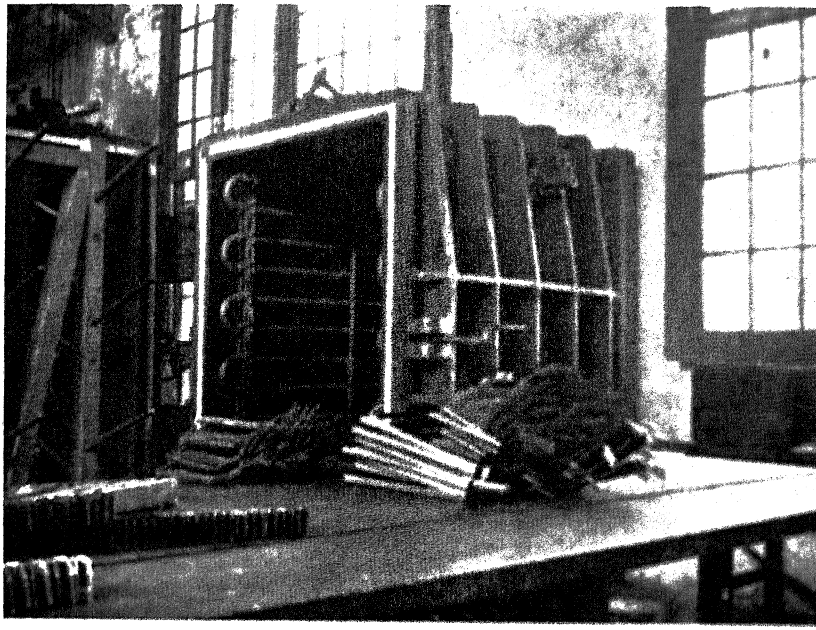


FIG. 114.—Vacuum Drying Oven at the Works of the British Westinghouse Co. at Trafford Park, Manchester.

alternate half-hour. If the air is dried out before admission to the vacuum chamber, it will hasten the process. It is evident that by means of vacuum ovens, a given degree of drying may be obtained with much lower temperatures than would otherwise be required, and this may be of importance for some materials. The use of vacuum ovens is generally found to greatly decrease the length of time required by the drying processes. The results are also much more satisfactory. Cotton coverings of copper wire contain from 5 per cent. to 15 per cent. of moisture, and this should be removed immediately before the wire is used.

Hence copper wire, in loose coils, should be thoroughly dried in a vacuum oven prior to being wound into armature coils or field spools. All cloths and papers should also be thoroughly dried before being dipped in impregnating varnishes. After dipping, they should again be placed in the drying oven. When the oven is coated with a non-conducting composition to prevent loss of heat by radiation, the consumption of heating steam is very small indeed. Owing to the vacuum, there is nothing but the article to be dried which can absorb the heat, and this, together with the radiation loss, is a measure of the heat required to be supplied. A drying oven some 220 metres in diameter and 350 metres long requires an expenditure of some $\frac{3}{4}$ h.p. from the air-pump while maintaining the vacuum against leakage into the oven. When first exhausting the oven, some $1\frac{1}{2}$ h.p. is customary. Some 25 kgs. of steam per hour would be ample for maintaining such a vacuum oven, if jacketed, at a temperature of about 75° Cent.

Untreated cloths or fabrics should be dried in a vacuum

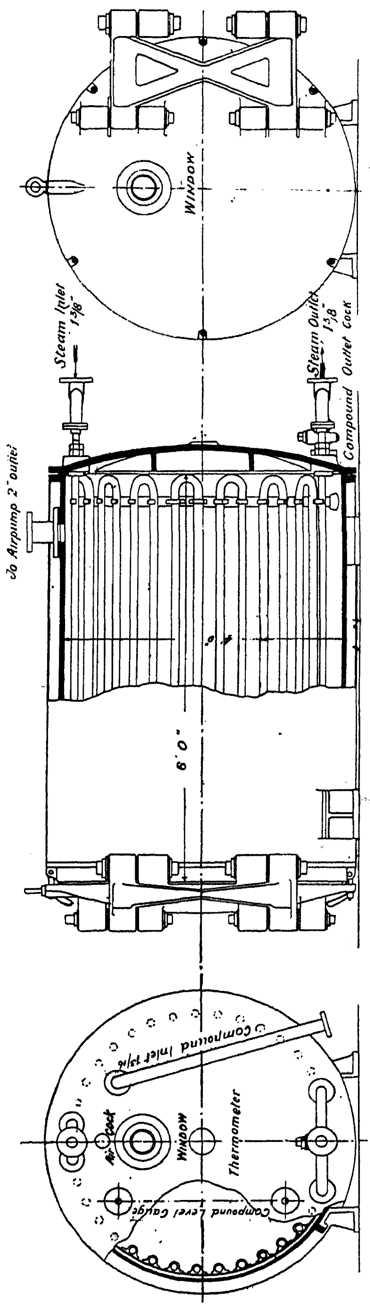


FIG. 114A.—Horizontal Vacuum Chamber for Drying only, or for Drying, Insulating, and Impregnating.

oven before being impregnated with insulating compounds. If the vacuum drying is deferred until after having treated the cloth, it tends to cause the impregnating compound to leave the fibre.

An equipment consisting of four medium-sized vacuum ovens installed in a Continental dynamo factory is shown in fig. 113.

A vacuum drying oven installed at the British Westinghouse works at Manchester is shown in fig. 114. The steam heating pipes are seen within.

An additional useful accessory is a dipping tank, in which the articles from which the air has just been completely exhausted may be immersed while still warm. The impregnating material in the tank is thus sucked up into the remotest pores, and subsequent access of air is thus rendered impossible.

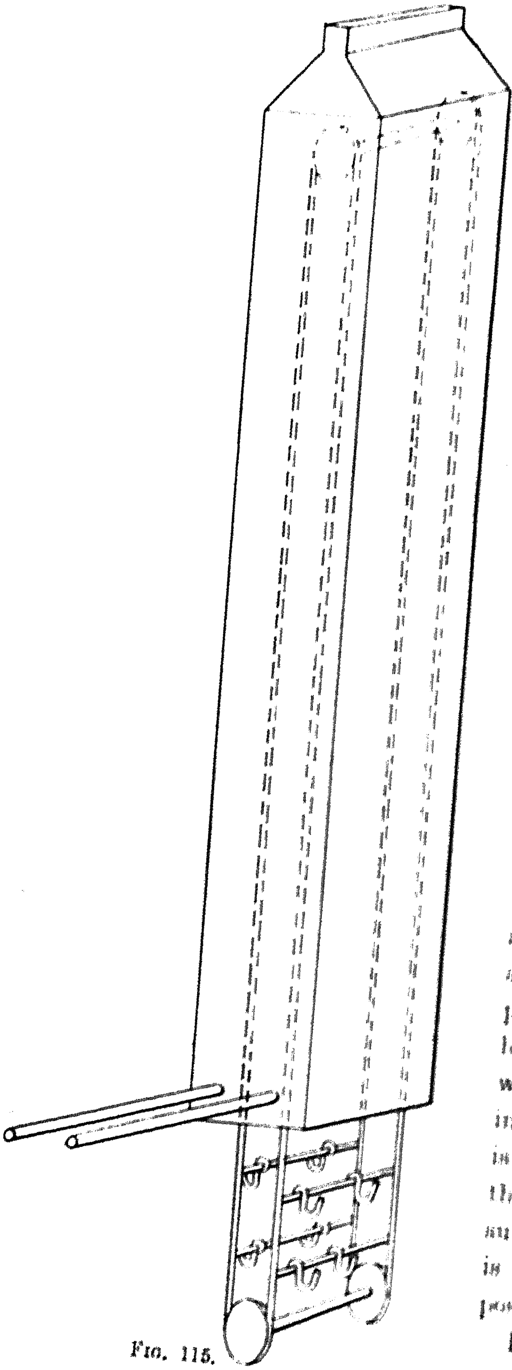


Fig. 115.

Fig. 114A illustrates a horizontal vacuum

oven of another type. It may be employed for drying only, or for drying, insulating, and impregnating. The chamber consists of a cast-iron cylindrical body, 4 feet internal diameter, 6 feet internal length, with a sheet-iron insulating jacket. The front cover opens on hinges and has a window to enable the process to be watched from without. The back cover is fast, and to this the usual fittings, as also a flexible metallic pipe to connect with a tank containing the insulating compound, are attached. The compound is drawn up by the vacuum, and runs back to the tank when air is let into the chamber. A spiral steam heating coil surrounds the inside. Articles to be impregnated are put into a tank, preferably on wheels, and a flexible pipe connected to that of the back cover allows the compound to flow into it to the height that may be required for covering them, thus avoiding coating the heating coil. The approximate weight of the chamber is 48 cwt.[1]

A chimney type of drying oven for armature and field coils is sketched in fig. 115.

[1] For particulars of their vacuum ovens, the authors are indebted to the courtesy of the firms, Messrs Emil Passburg, Berlin, and Messrs Neville Bros., Liverpool.

CHAPTER XXI

OTHER TOOLS AND ACCESSORIES EMPLOYED IN INSULATING

Tools for Cutting Insulations.—Ordinary knives and hand shears are employed by the winders for cutting insulations, but in large shops a great deal of the insulation is cut to gauge wholesale and kept in stock. For this purpose hand shears of the type shown in figs. 116 and 117, and power shears of the type shown in fig. 118, are employed. Treated cloth may be cut on the bias, if cut first into five- or six-foot lengths and repeatedly folded.

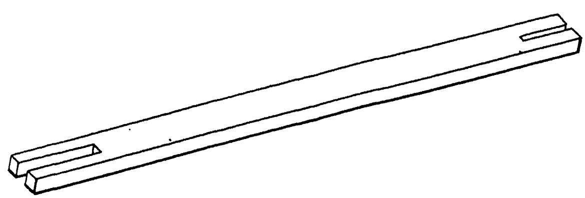


FIG. 120.—Wire Stripper.

For producing disc-shaped pieces of insulation, circular shears of the type illustrated in fig. 119 may be employed.

Wire Strippers.—In preparing armature coils it is necessary to strip and tin the ends of the leads. A very simple tool for the purpose of stripping the ends is shown in fig. 120. It consists of a flat piece of steel, some 3 mm. thick by 12 mm. wide and about 150 mm. in length. Saw cuts are made in the ends, and the tool is then hardened. The crotch spans the wire, and the sharp corners cut or strip off the insulation very easily. The wire is supported on a block of wood or fibre while thus being stripped.

Trimmer for Slot Insulations.—For ease in assembling the coils in the slots, the slot linings of presspahn, fuller board, horn fibre,

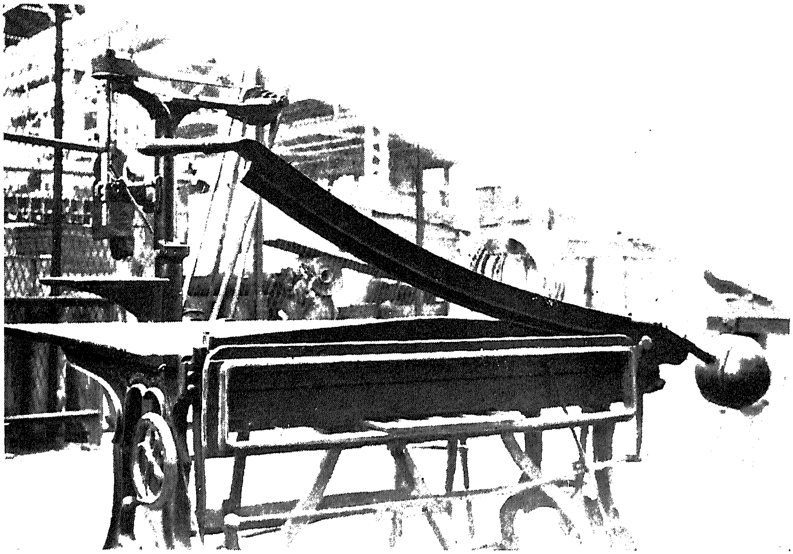


FIG. 116.—Hand Shears for Paper, Cloth, Fibre, etc.

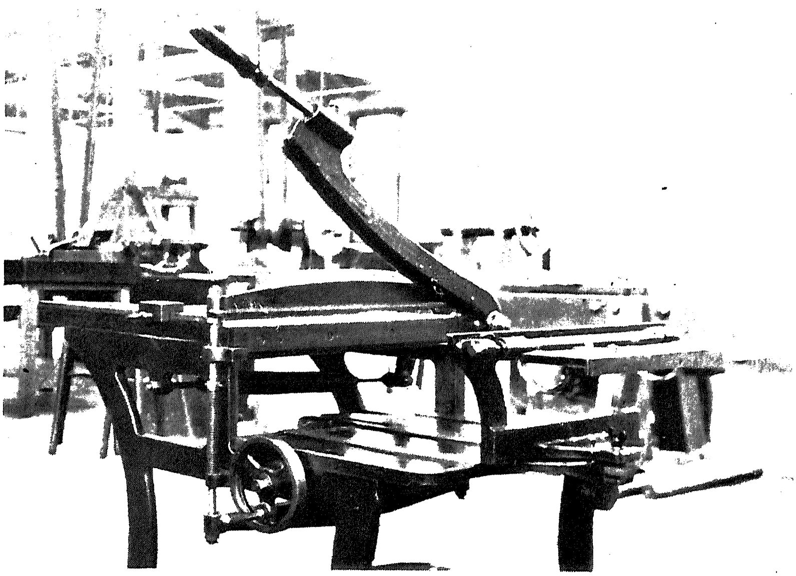


FIG. 117.—Hand Shears for cutting Micanite, Asbestos, etc.

[*To face* p. 248.

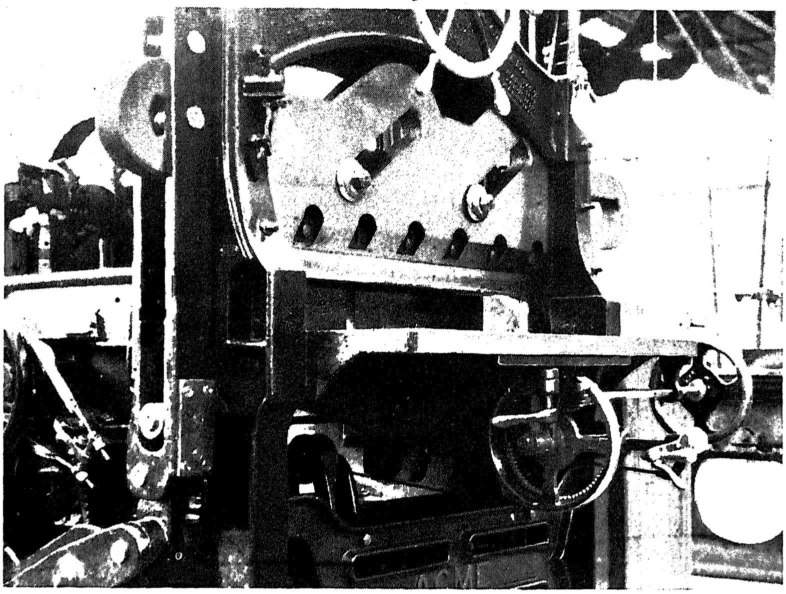


FIG. 118.—Power Shears for cutting Cloth, Paper, Fibre, and other Insulating Material *en masse.*

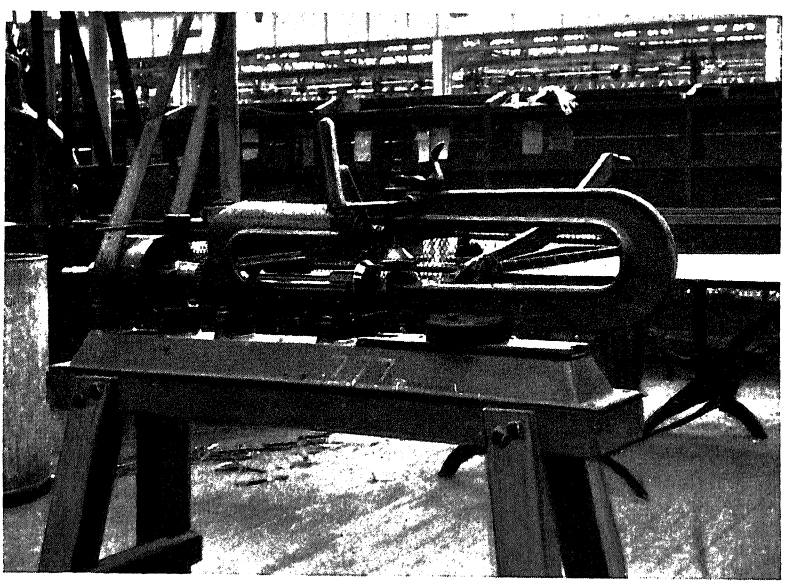


FIG. 119.—Circular Shears for cutting Disc-shaped Pieces of Paper, Cloth, and Fibrous Materials in general.

[*To face* p. 248.

or other material, are at first allowed to project above the surface of the armature, and, after the coils are all in place, the surplus is trimmed away, level with the surface. A knife is apt to slip and cut the slot insulation, or even the insulated coil, and never leads to neat results. Fig. 121 shows a trimmer which obviates these

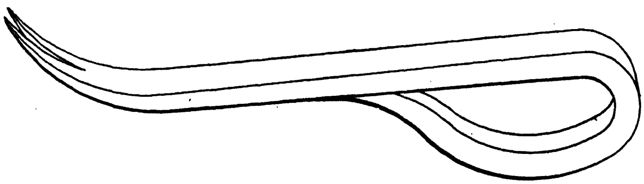


FIG. 121.—Trimmer for Slot Insulations.

difficulties. The V-shaped tool is pushed along the top of the slot, cutting away clean and smooth the projecting edges of the slot lining.

Tools and Accessories Employed in the Mica Department.

Mica Splitting.—There are required a common knife with well-sharpened and pointed blade; a file about 30 cm. long, or a strip of sandpaper; and a wooden block measuring about 20 cm. × 30 cm. × 5 cm. In addition to these, there are only required receptacles for the block mica and the split mica. The outfit is shown in fig. 122.

An edge of the block mica is first rubbed on the file to obtain a good bevelled edge, and then, while held in the left hand, it is placed on the block. The pointed knife is manipulated with the right hand, the point being inserted on the bevelled edge side of the block mica, and the laminations are loosened by a slight twist of the knife blade and thrown aside. The operation is repeated until the entire block is split up into leaves of a thickness of from 0·02 to 0·03 mm. An experienced girl can split 5 or more kilograms daily, the amount also depending upon the size and quality of the mica. It is a mistake to let the inducement of the lower price per kilogram lead to the purchase of very small blocks of mica, for the greater expense of splitting and handling will lead to a greater ultimate expense than would result from the employment of larger and better blocks. Block mica measuring about

5 cms. × 7·5 cms. is most generally employed, and the price ranges from 15d. to 33d. per kilogram. A size of about 7·5 cms. × 12 cms. is also often used, and costs from 40d. to 60d. per kilogram. Mica blocks are of irregular shape, as it is not worth while to trim them. When re-constructed from the thin splittings, with suitable attention to staggering the overlaps, a very regular product is readily obtained.

In some cases, it is the practice to first pass the block mica between bending rollers, as indicated in the sketch in fig. 123, but it does not appear that enough is gained to make this desirable.

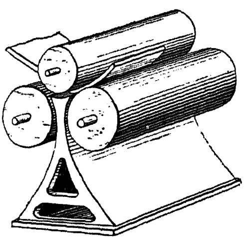


FIG. 123.—Rolls for bending back and forth blocks of Mica prior to splitting.

Nowadays, it hardly pays a large firm to do its own mica splitting, as the split India mica can be bought almost as cheap, if in fact not cheaper, than the block mica, on account of the cheap labour of India. But sometimes this mica is split altogether too fine, causing much loss of time in disengaging the leaves which adhere together closely, and there is considerable waste caused by pulverisation during transport. A machine for splitting mica is being used by a large American firm. It not only splits but assorts the different grades of thicknesses. This machine consists of a horizontally revolving disc, carrying blades on the safety razor plan, which shave off a leaf at each revolution, there being four blades of varying adjustments as regards thickness per cut. Four receptacles are provided for the four grades of mica, and four places to insert the block mica, the revolving knives being held against the mica by springs.

Micanite Building.—There are required a zinc-lined bench, a can and brush for the sticking varnish, receptacles for the mica, and thin cheap paper for backings. The outfit is shown in fig. 124. The can, of about one litre capacity, should be of zinc or similar metal. Iron will not do, on account of the chemical action of the sticking varnish, or its solvent, rusting and eating into the metal. A wire fastened across the middle to the rim is useful to brush against, to reduce the quantity of varnish which the brush takes up at each dipping. The brush should be of the flat variety, with bristles, say, 8 cms. long, well fastened into the socket, which is

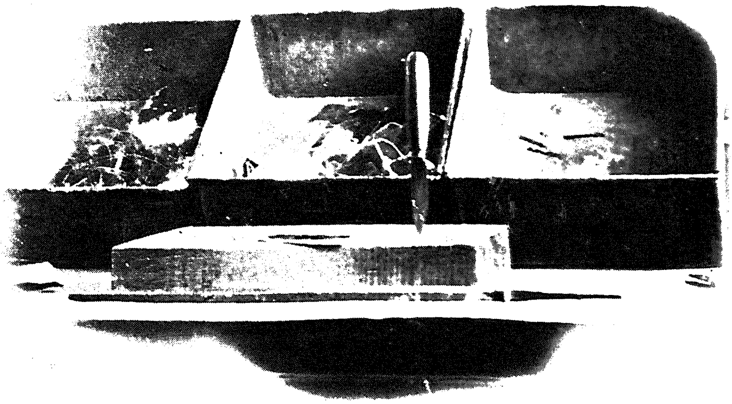


Fig. 122.—Tools and Accessories for Mica Splitting.

Fig. 124.—Tools and Accessories for Micanite Building.

[*To face* p. 250.

about 6 cms. wide. The sticking varnish may be composed of shellac gum, dissolved in the best alcohol (methylated spirit, on account of its corrosive tendencies, is to be avoided). The varnish should have a specific gravity of, say, 0·84 for micanite intended for commutator segment insulations, and about 0·88 for moulded mica work.

Copal varnish, zinser, and various other stickers are being used, but we consider shellac to be superior to other bonds for this purpose It is better that the Mica Department should mix its own shellac daily, according to requirements; and to this end, a keg with a shaft passing midway and parallel to the heads, suitably mounted in supporting bearings and with a tight-fitting clamped-

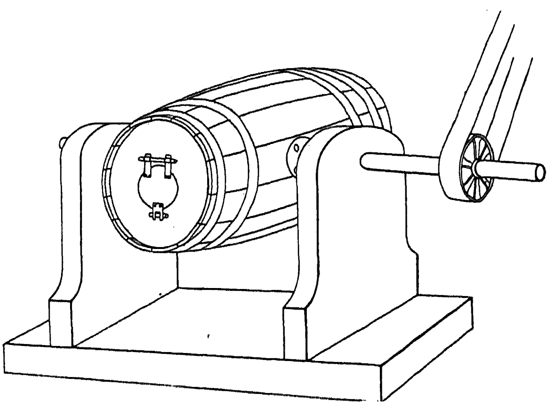


FIG. 125.—Revolving Keg for mixing Shellac.

on cover over a 15-cm. hole in one head. The shaft is revolved from a suitable source of power, and causes the keg to tumble about the shellac and solvent until they are thoroughly mixed. It is not advisable to make more than a two-days' supply, on account of the fermentation and evaporation of the alcohol. Shellac of the right consistency has a bright, clear, pale-reddish colour.

In fig. 126 is shown a photograph of the department of the Mica Insulator Co.'s works, in which micanite is built up from split mica. After the micanite plates have been built up to the required thickness, they are placed in a press, with separating sheet iron placed between each sheet, and pressed cold, gradually increasing the pressure, say, every two hours. Some firms lay the

sheets on a hot plate for three or four minutes, and then roll, with a 200-lb. roller, until the shellac has been spread out uniformly, the rolling being done on a cold plate. Such an equipment is shown in fig. 127. Others apply pressure and heat at the same time by means of hydraulic or toggle-jointed presses and steam-heated press plates.

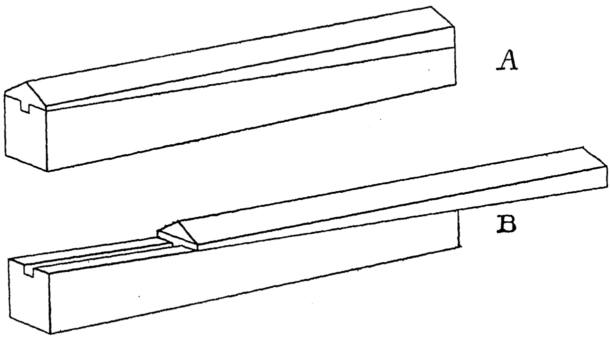


FIG. 136.—Wedge for Micanite Mould.

In fig. 128 is shown a photograph of a motor-driven, steam-heated, toggle-jointed micanite press at the works of the British Westinghouse Co., and in fig. 129 a hydraulic press, for the same purpose, at the Mica Insulator Co.'s works. The authors wish to express their thanks for the courtesy of these two concerns in

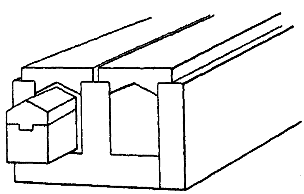


FIG. 137.

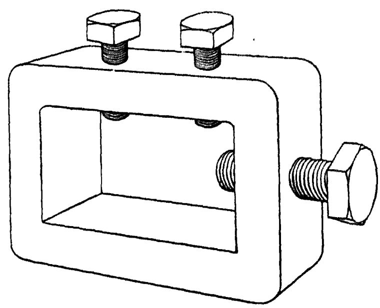


FIG. 138.

permitting them to employ these and other photographs in this treatise. A toggle-jointed hand-power press for micanite pressing is shown in fig. 130. This is also from a photograph taken at the British Westinghouse Co.'s works.

The commutator segment insulations are then passed through a mill, which grinds them to the required thickness. This mill con-

FIG. 126.—The Micanite Building Department of the Mica Insulator Co.

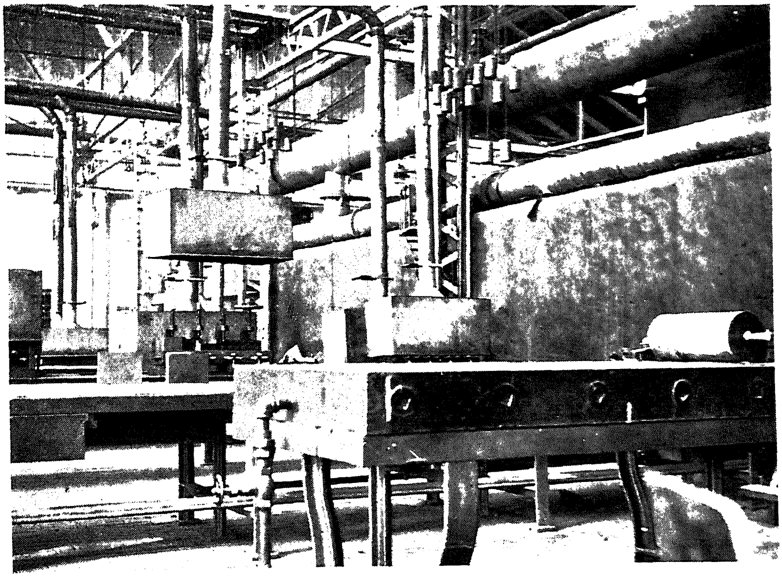


FIG. 127.—Plate and Roller employed in Manufacturing Micanite Sheets.

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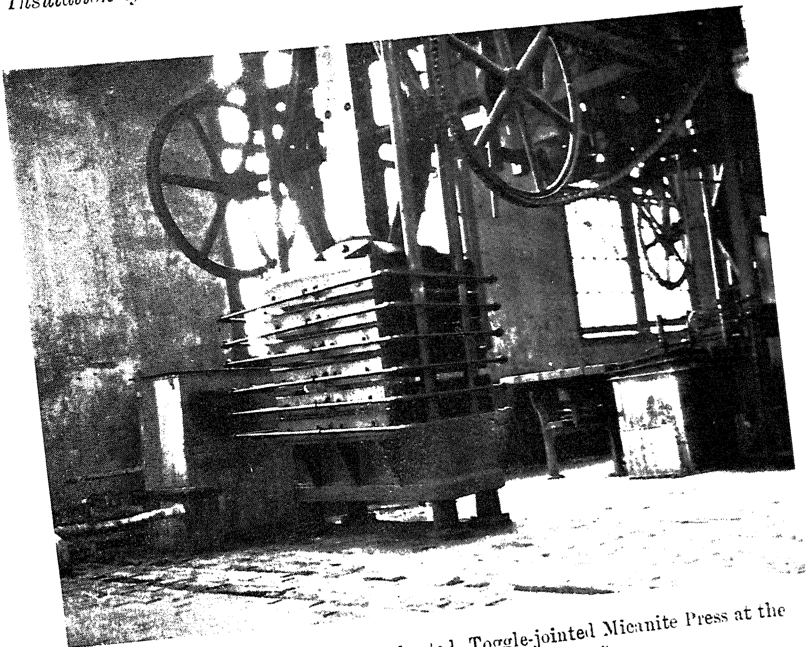

FIG. 128.—Motor-driven, Steam-heated, Toggle-jointed Micanite Press at the Works of the British Westinghouse Co.

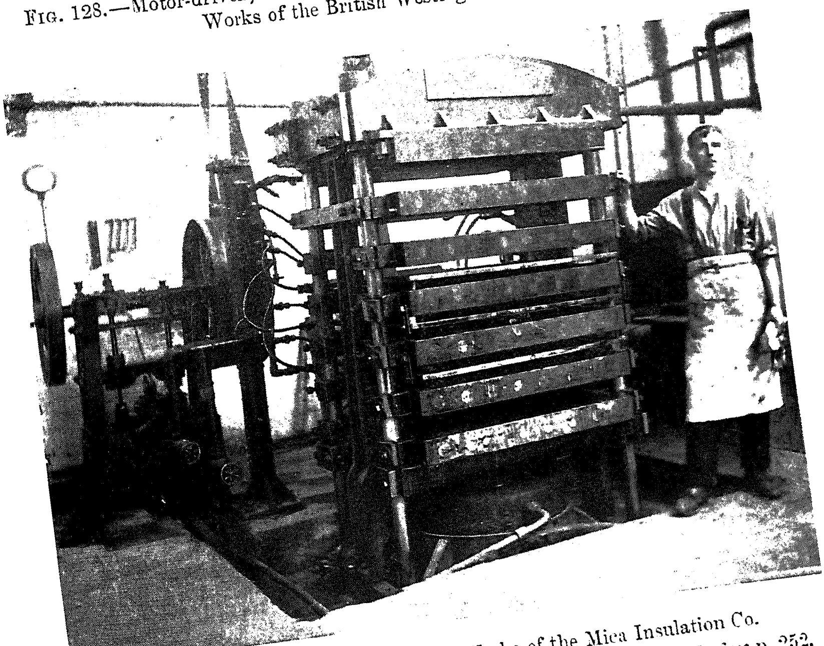

FIG. 129.—Hydraulic Press at the Works of the Mica Insulation Co.

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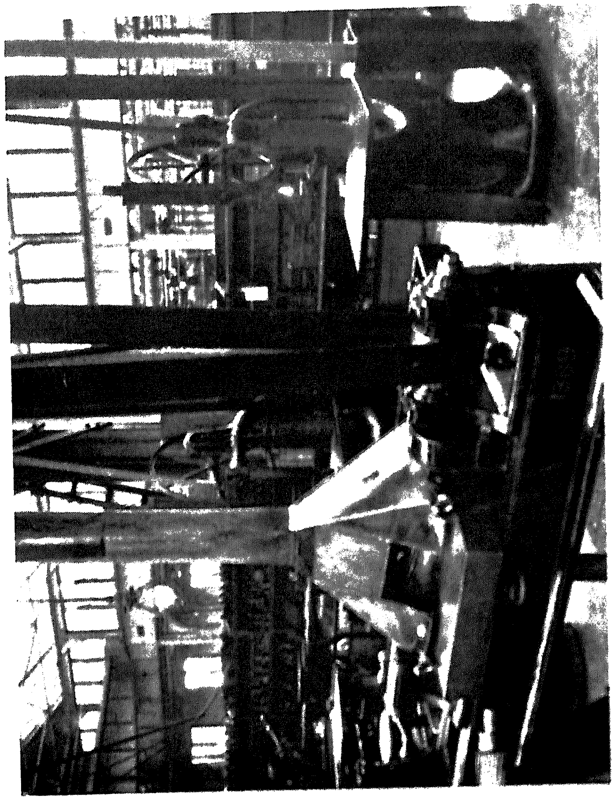

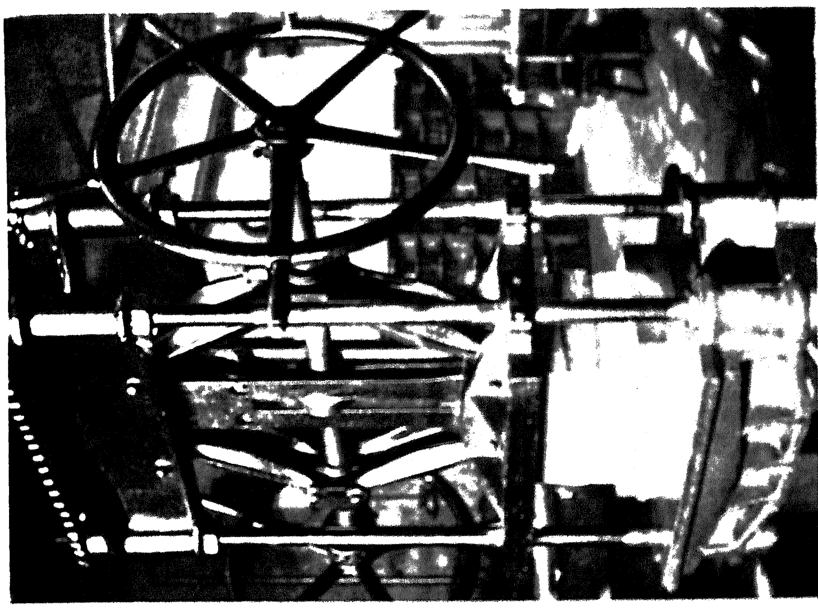

[To face p. [illegible]

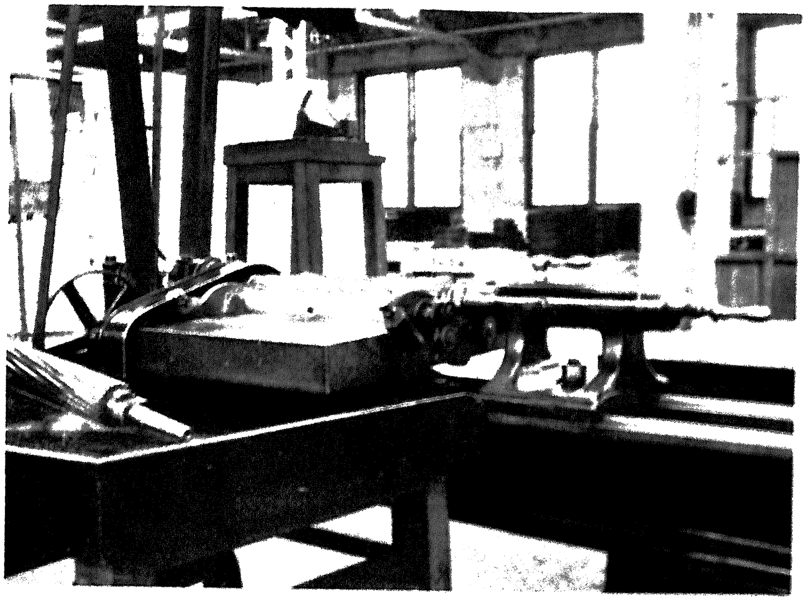

FIG. 132. Machine for Milling Micanite, with Suction Pipe and Hood [illegible] to permit of more clearly seeing the Cutter and the Feed Rollers.

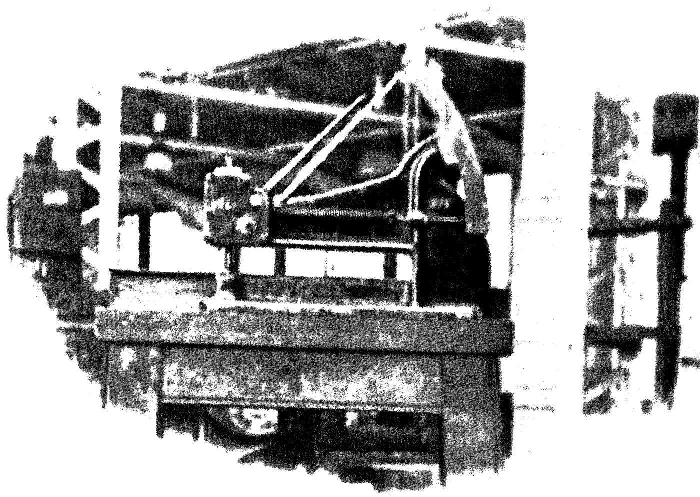

FIG. 133. Gauge for indicating the Thickness of Micanite Plates.

sists of a spirally cut steel roll, with well ground cutting edges mounted between lathe head and tail stock, an adjustable bed table located close below this cutter, and which can be raised or lowered by a finely threaded screw mechanism, and a burred roller located one on each side of the cutter, and geared thereto, for feeding in the micanite to the mill. Suction pipes and a hood serve to carry away the dust as rapidly as it forms. Such a micanite milling machine as employed at the British Westinghouse works is illustrated in figs. 131 and 132. The strips are ground to a

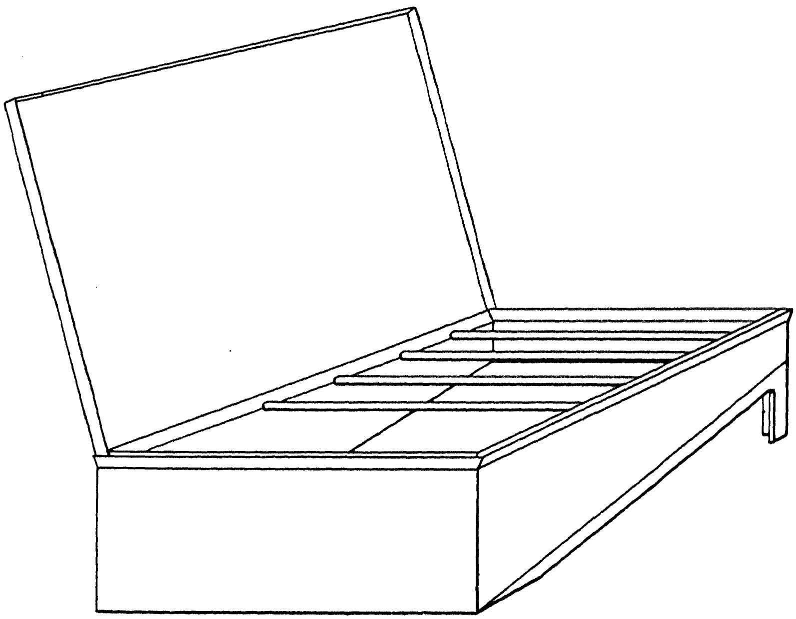

FIG. 139.—Dipping Tank with Cover open.

predetermined thickness. Practice alone dictates the allowances that must be made for compression when the commutator is assembled. This allowance varies with the size of segment and the amount of sticking varnish that can still be pressed out of the micanite during the process of assembling the commutator. The micanite plates are carefully gauged, and should not vary more than 0·025 mm. either way. A machine for gauging the thickness of the micanite plate is shown in fig. 133.

Micanite for commutator segment insulation, is cut up into blanks of a slightly larger dimension than the copper segment

and afterwards pressed in a hot press, as above described, until all but the thinnest possible film of varnish remains—barely enough to make the component plates adhere together. The sticking varnish can be more readily exuded from the mica strips when cut up to the size of segments than in the large plates as originally built up. A pressure of from 50 to 70 kilograms per square centimetre

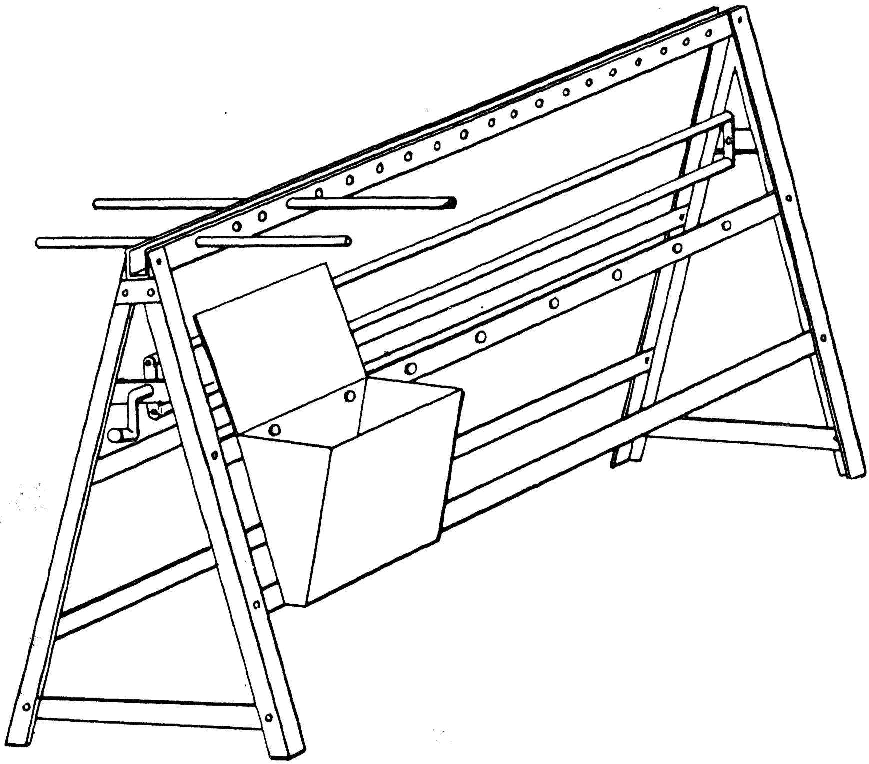

FIG. 140.—Rack for Dipping Tanks.

is advisable, and a steam pressure of about 7 kilograms per square centimetre may be employed to heat the plates.

Moulded Mica.—For moulded mica, white India mica should be pasted up with a heavier bodied shellac. The plate should be pressed and heated without expelling all the alcohol, for, in the case of moulded mica, it is necessary for flexibility. Here the object of pressing is not to expel the sticker, but merely to cause the shellac to flow evenly about between the layers of the plate. Heat is applied for perhaps three or four minutes, and then the

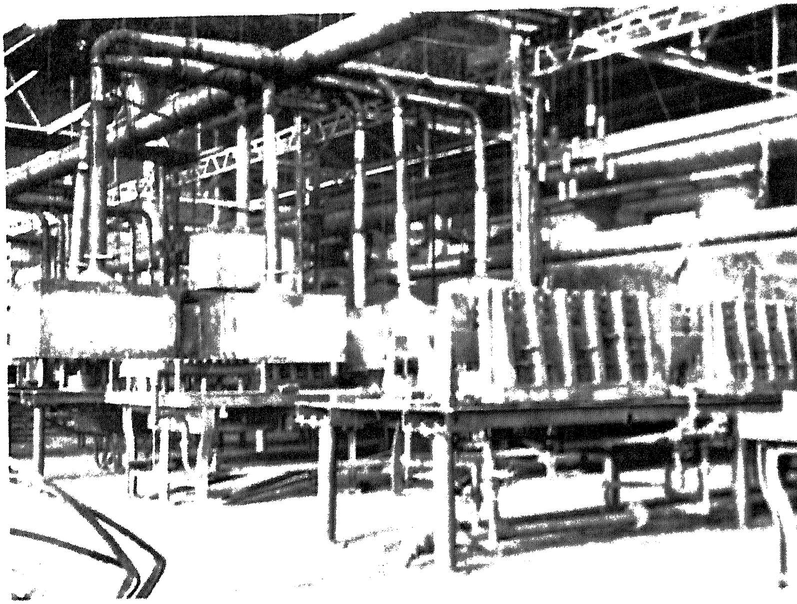

FIG. 134. Steam Presses employed in Micanite Moulding at the British Westinghouse Co.'s Works

FIG. 135. View of a Department of the Works of the Mica Insulator Co.

plate is pressed for about three minutes, but no longer, as the alcohol would evaporate too much. A pressure of 28 kilograms per square centimetre is sufficient. The moulds may be rubbed over with vaseline, to prevent the mica from sticking. A little French chalk will in some cases be sufficient. Some prefer to use thin mica, laid in loosely, to prevent the sticking of the mould. The moulds should be heated to from 150° to 180° C. over a Bunsen flame, this being preferable to steam heat, as it is more intense and shortens the time of baking. In fig. 134 is shown a

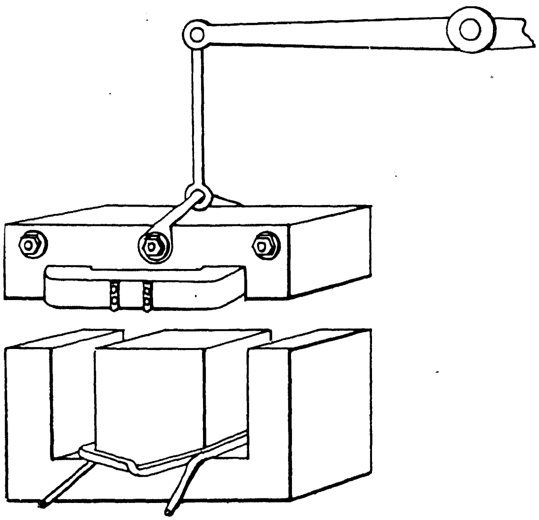

FIG. 141.—Transformer for testing for Faults in Form Wound Coils.

type of steam press suitable for use for a wide range of sizes of moulds. Such presses are piped for steam and cold water, so that they may be alternately heated and cooled. A gas grill in which gas and compressed air furnish the intense heat necessary for baking moulded mica stands next to a press over which the hoods are lowered and a blast of cold air is driven against the moulds. This method forms a quick and most satisfactory way of turning out moulded mica work on a large scale. The rotary fan for cooling purposes may be located on a high platform next to the roof, the cold air from outside being sucked in by the fan and blown through the system of pipes and finally upon the work as required.

Fig. 135 shows a view of another department of the works of the Mica Insulator Co. One sees on the left a press piped for receiving hot water.

The Manufacture of Slot Insulating Tubes.—A mandril, split and tongued lengthwise, as shown at A, in fig. 136, on p. 252, must be provided. The object of making it in two parts is so that the rolled-up insulation covering it, may be tightened up hard and fast, and also for convenience in removing the mandril after the insulating tube has been baked hard upon it.

Presspahn that has first been dried in a vacuum, and then

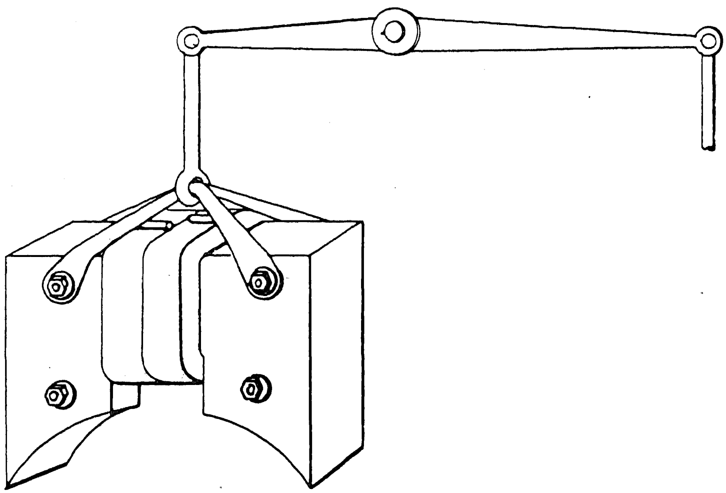

FIG. 142.—Transformer for testing for Faults in Armature Windings.

immersed in hot linseed oil for twenty-four hours, and then air-dried, is covered with a layer of mica for two-thirds of its length. The remaining one-third, half at each end of the sheet, is left free from mica, in order that when the sheet is wrapped on the mandril, there shall be a good adhesion of the first and last turn. This will result in the tube preserving its form. The mandril should be extended, as shown at B, in fig. 136, and thin Japan paper should be wrapped twice round it, in order to prevent the mandril from sticking. Then the presspahn-mica sheet is wrapped over the mandril, and temporarily fastened with friction tape. The mandril is then spread (in section) by hammering the ends or by otherwise pressing them in, until they assume the position shown at A in fig. 136.

The dimensions required for the tube, will determine the distance to draw out the mandril before rolling the insulating material upon it. The tube with the mandril inside is now placed in the baking mould, as shown in fig. 137. As will be seen, the mould is so designed that the tube may be formed to exact dimensions. Any undue pressure exerted, will bring the caps against shoulders, and thus prevent the tube being compressed to less than the desired dimensions.

The pressure is applied by means of wrought-iron straps, of the type shown in fig. 138. Three or four such straps are clamped outside of the baking mould, and the jig is then placed over a gas

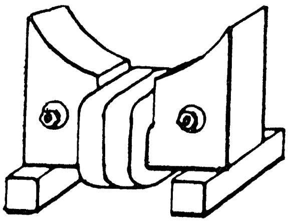

FIG. 143.—Transformer for testing for Faults in the Windings of Armatures of such small size as to be readily lifted about by one man.

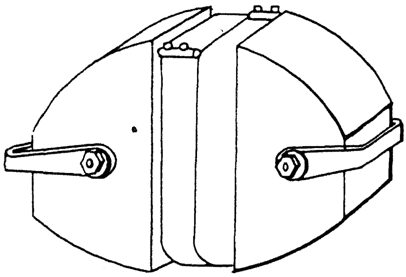

FIG. 144.—Transformer for testing for Faults in the windings of Stator Armatures. (Note the difference in the diameter of upper and lower surfaces. This enables the transformer to be used for armatures of two very different internal diameters.)

heater, the screws being tightened from time to time as the baking progresses. An application of heat for some twenty minutes generally suffices, and after the whole jig has been cooled by cold air blown against it for some ten minutes, the mandril should be slightly loosened. The strap-screws may now be slacked off, and the tube and mandril removed from the jig. The mandril having been previously loosened while quite warm, will now come out quite easily, especially if vaseline or oil has been applied to all parts of the mould and mandril before assembling them.

With two moulds of the type illustrated, one man can average at least six to eight tubes in an hour's time. The tube may be cut to the exact length required, and finally the ends should be

dipped in melted paraffin wax to a depth of about five centimetres, and held there for at least one half minute. This will prevent moisture gaining access to the ends of the tubes, which is a point of great importance.

Dipping Tanks. Armature coils which have braided sleeves over the tinned leads, may be required to be dipped in any of several different varnishes according to the particular purpose in view.

It is desirable to arrange the dipping tanks in a neat and orderly manner, and with a minimum of varnish, and with due

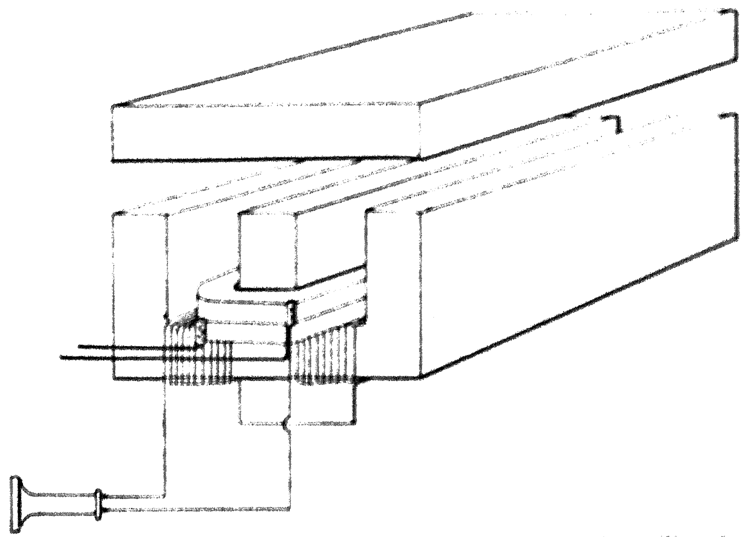

FIG. 145.—Transformer with Telephone, for testing for Faults in Form Wound Coils for Armatures and Fields. (Taken from *Elec. Club Journal* for March 1904, p. 136.)

regard to preventing undue evaporation of the solvent, and to guarding against fires.

Fig. 139 illustrates a floor tank, with cover open. Loose gas-pipe rods are employed for supporting the dipped coils. The cover is hinged, and kept shut, except when the tank is in service. Should fire danger occur, the rods are knocked off the ledge, letting the work drop into the tank together with the rods, and the cover is closed. The bottom of the tank is inclined for convenience in drawing off the varnish.

Fig. 140 shows a rack upon which individual tanks are hooked, and rods thrust through the top rail support the work before and

after dipping. The covers of all the tanks may be closed by a quarter turn of the crank at the end of the frame.

Testing Appliances.—Familiar testing appliances are illustrated in figs. 141 to 145. It is important to test the windings as frequently as possible during the various stages of manufacture.

CHAPTER XXII

SPECIFICATIONS FOR INSULATION

It is difficult to devise suitable tests for ensuring that t insulation employed in a given piece of apparatus is sufficient withstand the strains to which the apparatus will be subjected actual service. The strains in service may be due to "overheati dirt, moisture, chemical exposure, mechanical injury, or wear d to vibration, and sometimes to lightning or over-potential stres This is pointed out by P. H. Thomas in a paper entitled "T Testing of Electrical Apparatus for Dielectric Strength" (*A Inst. of Elec. Engrs.*, July 1, 1903). Mr Thomas continues: "Thus the voltage time test, which is usually applied to electric apparatus, by no means reproduces all the conditions of actu service. On the other hand, it is, of course, true that apparat which will stand a high disruptive test will usually stand bett in service, so that such a test is of value."

Tests with alternating currents are more severe on insulati materials than continuous-current tests of equivalent maximu potential, because of the additional heat produced by dielectr hysteresis.[1] Insulations are weakened by high temperatures a

[1] This is a disputed point. But Skinner's tests, the results of which a plotted in fig. 29, indicate a considerable difference in the dielectric l measured at different frequencies.

"While the laws of magnetic hysteresis are fairly well understood and t magnitude of the effect known, the phenomenon of dielectric hysteresis is st almost entirely unknown.

"It is quite probable that the loss of power in the dielectric in an alternati electrostatic field consists of two distinctly different components, of which t one is directly proportional to the frequency, analogous to the magne

continued applications of high potentials, so that it is customary to stipulate the length of time during which the break-down potential shall be applied. One minute is the time generally specified. In some cases, specifications call for tests of half-hour and more duration of application of the high potential voltage. Nowadays such long tests are generally considered undesirable, since they may lead to needless injury to the apparatus. Quite satisfactory results may be ensured with suitably drawn specifications, and a shorter time of application of the test. It is customary to apply for one minute, a break-down test of from two to five times the voltage of the machine or apparatus.

Mr P. H. Thomas's paper above referred to, enumerated, as follows, the objections to "over-potential" tests on completed apparatus:—

"1. A disruptive test fails partially of its object in testing the fitness of the apparatus for actual service, because the conditions of the test do not approximate closely the conditions of the service, either normal or emergency conditions.

"2. Serious injury may be done to the insulation of the apparatus by the test, even under apparently favourable conditions, so that failure is more likely to result in subsequent actual service.

"3. In making tests on finished apparatus, it is impossible to test each portion of the insulation separately; and since many types and forms of insulation go to make up the resultant insulation of the apparatus, it follows that only that part which is weakest with regard to the particular conditions existing at the time of the test, will be tested.

"4. In general, electrical apparatus is never in a condition so poorly adapted to stand dielectric strains as when first installed.

"5. Insulation tests require special testing apparatus, and expert and *experienced* direction, which are very often not available, and without which great risk is run in attempting such tests."

In further considering paragraph (1), Mr Thomas points out that the potential strains upon dielectrics cause effects of two kinds:—

hysteresis, and that a constant loss of energy per cycle, independent of the frequency, analogous to the loss of power by eddy currents in the iron, and also loss of energy per cycle proportional to the frequency."—Steinmetz, *The Theory and Calculation of Alternating Current Phenomena*, 2nd edition, p. 145.

"(a) A constant tendency to puncture the dielectric, which is due to the presence of the potential, and depends on the physical dimensions and nature of the dielectric, and which probably remains constant as long as conditions are unchanged, *e.g.* physical or chemical state. This strain is almost mechanical in its nature.

"(b) A tendency to heat or produce chemical change in the dielectric, largely the former. This is also due to the presence of voltage, and is very much more marked with alternating current than with continuous current. Though comparatively small in actual amount, this generation of heat is a dangerous thing, as it occurs within the body of the insulating material, which is usually a poor conductor of heat.

"Low-tension apparatus may be safely subjected to "over-potential" tests, provided care is taken, prior to the tests, to bring the insulation into good condition.

"But in high-tension apparatus much more serious conditions arise. A strain of double potential continued for any length of time, will, through the temperature rise occasioned by the energy losses in the insulating materials, strain the insulation far beyond any condition it will be called upon to undergo in actual service.

"In testing finished apparatus, it is manifestly impracticable to subdivide the windings into more than a very limited number of parts, *i.e.*, in case of the transformer, into more than generally four parts. When such a portion is subjected to disruptive test, a break-down may evidently occur in a number of ways, *i.e.* between portions insulated only by air distances; over a surface of insulating material, which may be marble on terminal block, fibrous material, or possibly the surface of oil in an oil-insulated piece of apparatus. Furthermore, break-down may occur through solid material, which in some places will be well ventilated, and in other places will not be well ventilated. Sometimes, portions of this material which in the disruptive test receives full strain, may, when running in commercial service, be so located as practically to receive a very much less strain. Such a point, for instance, would be the neutral point of a three-phase star-wound generator. It is thus clear that if the severity of a test (as it must necessarily

be) is determined by the strength of the insulation of the weakest spot of these various types and qualities of insulation, the other parts will receive an insufficient test. It may occur that a portion of the insulation less likely to give trouble in subsequent service, will be this weakest portion, and will determine the whole test, leaving the condition of the other more vital portions of the insulation, insufficiently tested.

"In tests made by persons inexperienced in such matters, there is grave danger of injury to apparatus, which would not result when tests are properly made. Such difficulty may arise by the use of testing apparatus having too high an inductive factor or field reaction, so that current to the apparatus may either raise the voltage beyond the usual ratio, or so deform the e.m.f. wave as to cause an excessive strain; or by making tests when insulation is not in good condition; or, in preliminary trials, in allowing tests to be on too long, though perhaps at a slightly lower voltage than the voltage of final test; or by improperly determining the temperature of the transformer; or in a number of other ways, unnecessary to enumerate. Difficulty from this source is of by no means rare occurrence, and it is very difficult to avoid in large, high-tension apparatus."

The Standardisation Committee of the American Institute of Electrical Engineers has drawn up the following recommendations for specifications relating to insulation tests: [1]—

"**Insulation.**—The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric (disruptive) strength, or resistance to rupture by high voltage.

"Since the ohmic resistance of the insulation can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high-voltage test for dielectric strength should always be applied.

"**Insulation Resistance.**—Insulation resistance tests should, if possible, be made at the pressure for which the apparatus is designed.

[1] *Proc. Am. Inst. Elec. Engrs.*, vol. xix.,—Report of the Committee on Standardisation, p. 1084.

"The insulation resistance of the complete apparatus must be such that the rated voltage of the apparatus will not send more than $\frac{1}{1,000,000}$ of the full load current, at the rated terminal voltage, through the insulation. Where the value found in this way exceeds 1 megohm, 1 megohm is sufficient.

"**Dielectric Strength.**—The dielectric strength, or resistance to rupture, should be determined by a continued application of an alternating e.m.f. for one minute. The source of alternating e.m.f. should be a transformer of such size that the charging current of the apparatus, as a condenser, does not exceed 25 per cent. of the rated output of the transformer.

"In alternating-current apparatus, the test should be made at the frequency for which the apparatus is designed.

"The high-voltage tests should not be applied when the insulation is low, owing to dirt or moisture, and should be applied before the machine is put into commercial service.

"The high-potential test should be made at the temperature assumed under normal operation.

"It should be pointed out that test at high voltages, to determine whether specifications are fulfilled, are admissible on new machines only.

"The test for dielectric strength should be made with the completely assembled apparatus, and not with its individual parts, and the voltage should be applied as follows:—

"1. Between electric circuits and surrounding conducting material, and

"2. Between adjacent electric circuits, where such exist, as in transformers.

"The tests should be made with a sine wave e.m.f., or, where this is not available, at a voltage giving the same striking distance between needle-points in air as a sine wave of the specified e.m.f., except where expressly specified otherwise. As needles, new sewing-needles should be used. It is recommended to shunt the apparatus during the test by a spark gap of needle-points set for a voltage exceeding the required voltage by 10 per cent.

"A table of approximate sparking distances is given at end of this report.

"The following voltages are recommended for apparatus, not including transmission lines or switchboards:—

Rated Terminal Voltage.	Rated Output.	Testing Voltage.
Not exceeding 400 volts . . .	Under 10 kw. .	1,000 volts.
" " . . .	10 kw. and over	1,500 "
400 and over, but less than 800 volts	Under 10 kw.	1,5C0 "
400 " " 800 "	10 kw. and over	2,000 "
800 " " 1,200 "	Any . . .	3,500 "
1,200 " " 2,500 "	Any . . .	5,000 "
2,500 " " 10,000 "	Any . . .	Double the normal rated voltage.
10,000 " " 20,000 "	Any . . .	10,000 volts above normal rated voltages.
20,000 "	Any . . .	50 per cent. above normal rated voltages.

"Except that transformers of 5000 volts or less, directly feeding consumption circuits, should be tested at 10,000 volts.

"Synchronous motor fields, and fields of converters started from the alternating current side, 5000 volts. Alternator field circuits should be tested under a break-down test voltage corresponding to the rated voltage of the exciter, and referred to an output equal to the output of the alternator, *i.e.* the exciter should be rated for this test, as having an output equal to that of the machine it excites.

"Condensers should be tested at twice their rated voltage, and at their rated frequency.

"The values in the table above, are effective values or square roots of mean square (R.M.S.), reduced to a sine wave of e.m.f.

"In testing insulation between different electric circuits, as between primary and secondary of transformers, the testing voltage must be chosen corresponding to the high-voltage circuit.

"In transformers of 20,000 volts upwards, it should be sufficient to test the transformer by operating it at 50 per cent. above its rated voltage; if necessary, with sufficiently higher frequency to induce this voltage.

"The test of the insulation of a transformer, if no testing transformer is available, may be made by connecting one terminal of

the high-voltage winding, to the core and low-voltage winding, and then repeating the test with the other terminal of the high-voltage winding so connected.

" High-voltage tests on transformers or other apparatus, should be based upon the voltages between the conductors of the circuit to which they are connected.

" When machines or apparatus are to be operated in series, so as to employ the sum of their separate e.m.f.'s, the voltage should be referred to this sum, except where the frames of the machines are separately insulated both from ground and from each other.

" The insulation between machines, and between each machine and ground, should be tested, the former referred to the voltage of one machine, and the latter to the total voltage of the series."

TABLE XLV.—SPARKING DISTANCES IN AIR BETWEEN OPPOSED SHARP NEEDLE-POINTS, FOR VARIOUS EFFECTIVE SINUSOIDAL VOLTAGES, IN INCHES AND IN CENTIMETRES.[1]

Kilovolts, Square Root of Mean Square. R.M.S.	Distance.	
	Inches.	Cms.
5	0·225	0·57
10	0·47	1·19
15	0·725	1·84
20	1·0	2·54
25	1·3	3·3
30	1·625	4·1
35	2·0	5·1
40	2·45	6·2
45	2·95	7·5
50	3·55	9·0
60	4·65	11·8
70	5·85	14·9
80	7·1	18·0
90	8·35	21·2
100	9·6	24·4
110	10·75	27·3
120	11·85	30·1
130	12·95	32·9
140	13·95	35·4
150	15·0	38·1

The recommendations of the *Verband Deutscher Elektrotechniker* regarding the insulation of electrical machinery, are as follow :—

[1] Issued by the American Institute of Electrical Engineers.

Insulation.—Measurements of the ohmic insulation resistance will not be prescribed. Tests of the disruptive strength shall be made at the factory, and in the case of large machines, again at the place of erection before putting the machine in service. Machines and transformers must be able to withstand for half-an-hour, the application of a voltage a specified amount in excess of their normal rated voltage. The magnitude of this testing voltage is specified in the following paragraph. The test is to be made on the machine when hot, and is only in exceptional cases to be repeated on a later occasion, in order that the danger of subsequent injury to the machine may be avoided.

Machines and transformers up to 5000 volts, shall be tested with double their normal voltage. Machines and transformers for from 5000 volts to 10,000 volts shall be tested with 5000 volts higher than their normal voltage. For machines for 10,000 volts and more, the testing voltage shall be 50 per cent. in excess of their normal voltage.

These testing voltages are to be applied across the insulation between windings and frame, and between electrically independent windings. When, in the latter case, the windings are for different voltages, the testing voltage is derived by the preceding clause from the winding of the highest voltage as a basis.

When machines or transformers are connected in series, then, in addition to the tests above prescribed, the connected system is to be tested against earth, with a testing voltage derived from that of the entire system as a basis.

These regulations for the testing voltage apply only in cases where the tests are made with current of the same kind as is employed in the windings when in service. When a winding, which in service carries continuous current, is tested with alternating current, then the testing voltage shall be taken at 0·7 times the above prescribed value. Conversely, if an alternating-current winding is tested with continuous current, the testing voltage must be 1·4 times higher than that above prescribed.

If, in service, a winding is conductively connected to the frame, this connection is to be removed for the insulation test. The testing voltage from such a winding to frame is to be derived from

the highest voltage which, in service, would exist between any point of this winding and the frame.

Separately excited field windings shall be tested with three times the exciting voltage.

The secondary windings of asynchronous motors are to be tested with double the starting voltage. Rotors with short-circuited windings need not be tested.

Mr H. F. Parshall's Suggestions for Testing Specifications.

In the first number (p. 4.) of vol. i. of *Traction and Transmission*, Mr Parshall, in an article entitled "Standardisation of Electrical Apparatus," described good practice in the matter of specifying insulation to be as follows:—

"*Insulation.*—The workmanship and mechanical handling of insulating material is such an important element in determining the final result, that an exact specification as to the kind of insulation or the thickness thereof may not ensure certain results.

"In the case of the magnets for all classes of machinery on account of induction discharges to which field magnets may be subjected, it is usual to use a greater thickness of insulation than in the case of armatures. Up to 500 volts it may be taken as standard practice to insulate both the field and the armature of stationary motors, and of machines not subject to extra hard usage, for double the working voltage.

"For street car motors and machines subject to like working conditions, it is usual to insulate the field and armature to withstand in the manufacturer's works five times the working voltage.

"In the case of extra high-voltage generators, *i.e.* from 3000 volts upwards, and transformers, the usual practical test is double the working voltage, or, at the works of the makers, from three to five times, as may be stipulated. The thickness of the insulation on the magnet coils, usually varies from $\frac{1}{16}$ in. to $\frac{3}{16}$ in., according to the size of the machine and voltage for excitation.

"In armatures, an approximate rule is that the insulation for a

500-volt armature be approximately ·05 in. in thickness, increasing approximately as the square root of voltage.

500-volt armatures . .	·05 insulation.
1,000 „ „ . . .	·071 „
2,000 „ „ . . .	·1 „
4,000 „ „ . . .	·142 „
10,000 „ „ . . .	·225 „

"The value of insulating should be determined from the puncturing voltage, and not from the insulation resistance. Insulation tests should be made with the machines clean and dry, with a sine E.M.F. curve, and at the normal working temperature. The duration of tests should be defined, and, in the ordinary case, should not exceed five seconds, since insulation subject to extra high pressure, deteriorates with the length of time it is subjected to such pressure.

"In the case of transformers, the thickness of insulation stipulated above, will ordinarily be found to be satisfactory, and the method of tests will apply. The voltage for the test, should have reference to the primary or maximum potential between the high-pressure coil and the core of the transformer."

Mr P. H. Thomas' Suggestions for Testing Specifications.

"No complete recommendations are here made for specifications for testing apparatus for dielectric strength, but a few suggestions will be offered on topics in which there is probably a considerable diversity of opinion.

"(*a*) In high-tension apparatus, *e.g.* 20,000 volts and above, only moderate short time over voltage tests should be specified in contracts.

"(*b*) Such tests should be made once for all when the apparatus is known to be in a good condition, preferably at the factory, by experts, to give assurance that the specification has been met. Such tests should not be made a second time.

"(*c*) After installation, a considerably lesser test should be made upon the apparatus, which will detect any serious injury in transportation and installation. Any moderate deterioration, due to

absorption of moisture, etc., will right itself with service, provided no abnormal deterioration has occurred.

"(*d*) It is preferable to make high-potential tests by increasing the voltage upon the apparatus as it is designed to operate, one terminal at a time remaining grounded, rather than making a high break-down test by voltage from an external source.

"(*e*) On tests of very high-tension apparatus, such as generators and transformers,[1] *no break-down gap should be used in connection with the determination of voltage.* Any error in the voltage of test, provided precautions as to the proper size of testing apparatus are used, will be comparatively unimportant. In some cases the voltage of the testing device may be determined by means of a spark gap before the apparatus to be tested is connected to the circuit.

"It must be borne in mind that in the above discussion the objections to over-potential tests and the dangers to apparatus involved only have been considered, and that it is not recommended that disruptive tests be abolished. Such tests may be, and regularly are, made successfully, and are very desirable to ensure good insulation in electrical apparatus, and to determine the fulfilment of specifications. The point it is desired to emphasise is, that great care should be taken to avoid injury to apparatus, and that excessively severe tests, especially long time tests at high-potential, should be avoided."

Mr Thomas also sets forth the following precautions to be observed in testing apparatus:—

"The most important precautions to be observed in making disruptive tests are here summarised:—

"(*a*) Insulation of all apparatus to be tested should be definitely known to be thoroughly dry.

"(*b*) All insulation surfaces and the apparatus in general should be clean, and free from all kinds of foreign matter.

"(*c*) The measurement of the insulation resistance will sometimes give an idea of the fitness of the insulation for test. This condition will usually be determined, not by the absolute value of the insulation resistance, but by a curve of the variation of insulation resistance as the apparatus is being dried out. When it has been increasing for a period, and finally becomes steady with

[1] This is important.

steady temperature, the drying operation is probably fairly complete. However, where air or oil spaces are included in the bulk of the insulating parts, these spaces may determine the insulation resistance, so that no indication is given of the condition of the actual solid material.

"(*d*) Before applying disruptive test, it should be definitely determined that the temperature of no part of the apparatus to be tested is above that at which the test is to be made, remembering that tests of apparatus when hot, especially when very hot, are extremely severe.

"(*e*) Electrical apparatus of large capacity, which necessarily contains considerable masses of iron and copper, lags behind the atmosphere in temperature changes; consequently, when the atmosphere is damp and warmer than the apparatus, there is a tendency for the latter to 'sweat,' or condense moisture upon its surface. This moisture will at least partially be absorbed by the insulation material, and render the apparatus unfit for test; consequently it is important in unpacking to open the packing-case only when the air is cooler than the apparatus. In the case of oil-insulated apparatus, the insulation should be protected from moisture when once dried out, until immersed, ready for service.

"(*f*) The determination of the high-tension voltage actually reached during the test is sometimes a difficult matter. The things to be avoided chiefly are the distortion of wave form, or the change in ratio of transforming apparatus, or excessive drop due to the use of apparatus for applying the testing voltage, which is of insufficient size to supply the charging energy required by the apparatus to be tested. This subject deserves a full consideration, but has been so fully discussed elsewhere that further space will not be given here.

"(*g*) In applying the potential of test to apparatus, the voltage should not be raised in the testing set to full value and then applied to the apparatus, but, after connection, should be increased rapidly by small steps, or continuously from a voltage not over one-half the final. Also the voltage should be raised so quickly that the time during which the last 10 per cent. or 20 per cent. of the voltage is being applied will be short, as compared with the duration of the full potential test.

"(*h*) *To prevent local concentration of potential* which results from any spark or break-down occurring near the apparatus to be tested when the latter contains coils; choke coils, static interrupters, or resistance in series with the terminal of the apparatus to be tested may be used. The result essential to the avoidance of this local strain is the prevention of the strain caused by the above-mentioned break-down from being transmitted without being smoothed out to the windings under test.

"Evidently, a choke coil in the lead of the apparatus will allow a change of potential to pass through it only slowly; and if this coil be made to have several times the choking effect of the smallest portion of the winding to be protected (next the terminal), which is considered to be able to stand the voltage of the test momentarily, the necessary protection will be obtained. It would seem that a resistance in the place of the choke coil would serve the same purpose, and, in a measure, undoubtedly will. However, since the resistance does not absorb voltage until after a considerable current strength has been attained, it is not as well adapted to protect from sudden changes of potential as the choke coil. The static interrupter being merely a choke coil whose power is increased by the use of the condenser, will act in the same manner as the choke coil described above. Usually, however, except where static interrupters are provided for other purposes, the choke coil will be found more convenient."

CHAPTER XXIII

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[1] For the preparation of this section of the bibliography, and also to a great extent for the preceding section, the authors are indebted to Mr H. D. Symons.

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APPENDIX

Some valuable investigations on insulating materials have recently been carried out by Dr Glazebrook at the National Physical Laboratory. The report has so recently appeared that it has been impossible to include the results in the body of this treatise. Through the courtesy of the Engineering Standards Committee, the authors are able to present the results in this Appendix.

The investigation was carried out by Dr Glazebrook at the request of the Electrical Plant Committee of the Engineering Standards Committee, and the experiments were superintended by a Sub-Committee of that body, with a view to assist in determining the temperature limits consistent with safe working of motors, dynamos and electrical machinery. The investigation will be best understood by quoting from the Report :

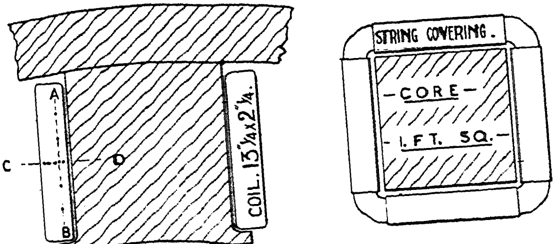
"The safe temperature will clearly depend on the electrical and mechanical properties of the materials, especially the insulators used in constructing the coils. Accordingly, a large series of insulating materials were obtained and heated for some three months to temperatures of from 75° C. to 100° C., 100° C. to 125° C., and 125° C. to 150° C. in electric ovens. These were tested for resistance, electric strength as measured by the volts required to pierce them, mechanical strength as measured by resistance to shear—produced by a carefully made punch—and capacity to resist bending. This last was tested by bending the specimen round a series of cylinders of gradually decreasing diameters, and noting the diameter of the cylinder at which the specimen broke.

"Table XLVI. shows some of the results.

"In the Table—

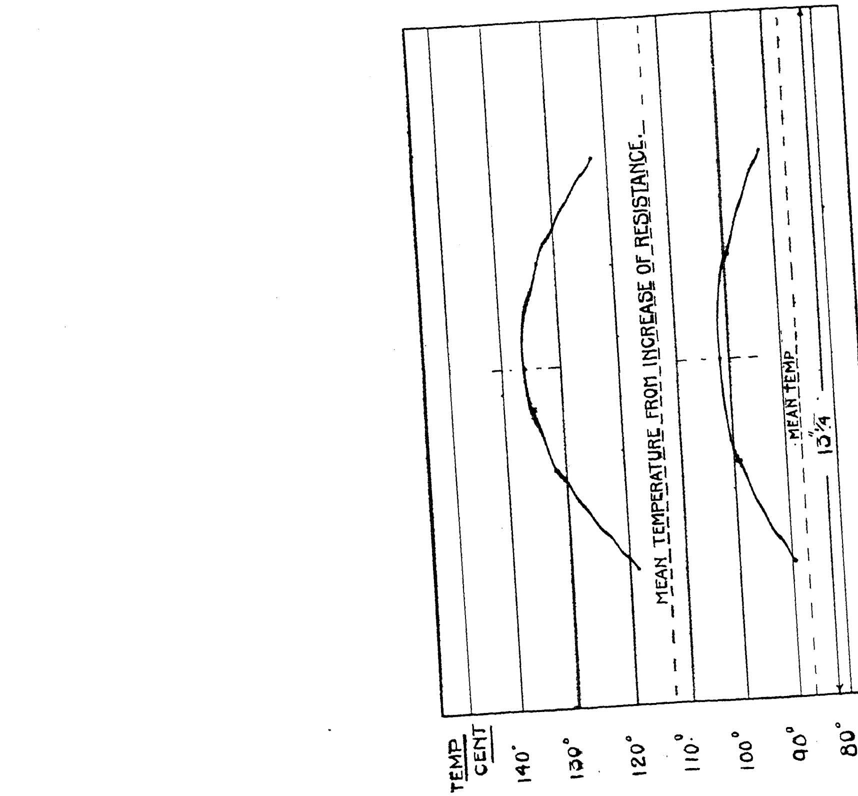
a	indicates that this specimen had not been heated.						
b	"	"	"	been heated to about			75° C.
c	"	"	"	"	"	"	100° C.
d	"	"	"	"	"	"	125° C.

"Speaking generally, the properties improve by heating to 75°, do



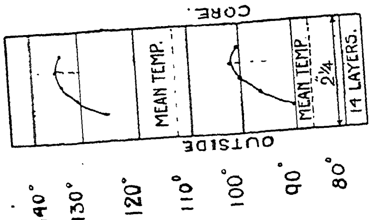
Sectional Elevation. Sectional Plan.

FIG. 146.—Researches on the Temperature of Dynamos.



Temperature Distribution on line A—B.

FIG. 146A.[1]—Researches on the Temperature of Dynamos.



Temperature on line C—D.

FIG. 146B.[1]—Researches on the Temperature of Dynamos.

[1] In figs. 146A and 146B the upper curves relate to the coil and core when tested at the Laboratory, the current being 8·1 ampères. The lower curves were obtained with the coils on a 500 K.W. machine when running, and with a field current of 8·2 ampères.

not seriously deteriorate by further heating to 100°—in some cases they actually improve—but showed a marked falling off on heating to 125°.

"The smallest cylinder used had a diameter of 1·6 mm., and an entry like 1·6 mm., 10 in the last two columns indicates that the specimen was bent ten times without breaking round this cylinder.

"But in the endeavour to apply these results, another difficulty occurred. The temperature of the coils used to be taken by means of a thermometer placed against them. This method is even nowadays often employed. The more modern practice is, however, to determine it from the resistance of the copper. But this gives the average temperature of the coil, and the breaking down is probably determined by the maximum temperature. Very little was known about the distribution of temperature in the coil beyond that contained in a valuable paper by Mr Brown.[1]

"Some eight or ten makers gave their help, and wound a number of field-coils of their ordinary pattern, but containing thermo-junctions of iron-eureka wire standardised at the Laboratory. The distribution of temperature in these coils was tested in the first place at the Laboratory by running the proper current through the coils and observing the temperatures as given by the twelve or fifteen thermo-junctions. The resistance of the coil was also measured, and thus data were obtained for finding the mean temperature and the distribution of temperature.

"When this was done the coil was returned to the maker's works, and the same observations made there during a test run of the machine.

"The experiments are still in progress, but figs. 146, 146A, 146B give the result for one coil.

"The diagram explains itself. Thus, when the coil was at the Laboratory carrying a current of 8·1 ampères, the mean temperature was 113° C. and the maximum 136° C., a difference of 23° C., while when used on a 500 K.W. machine, and carrying the same current, the mean temperature was 82° C. and the maximum about 103° C.

"The difference in these figures is due to the fanning action of the armature.

"I think the value of a series of experiments of this kind on eight or ten different types of machine, will be obvious to anyone interested in electric machinery, while cordial thanks are due to those manufacturers who have helped in the investigation. These experiments have been carried out by Mr Rayner."

[1] "The Rise of Temperature in the Field Coils of Dynamos," *Jour. Inst. Elec. Engrs.*, vol. xxx. p. 1159.

TABLE XLVI.

Substance.	Condition.	Disruptive Voltage.	Ratio of Max. Diff. from Mean to Mean.	Thickness mm.	Volts per mm.	Punching Pressure Kilogrammes.	Bending Test. Cylinder Diameter Millimeters.	Bending Test. Times without Breaking.
Presspahn	*a*	2180	9%	0·23	9500	25	...	...
	b	2330	6%		10000	26	1·6	10
	c	2330	6%		10200	12	19	...
Presspahn	*a*	2920	13%	0·56	5200	48	...	...
	b	3550	3%		6300	48	1·6	6
	c	3670	7%		6550	36	25	...
	d	3330	3%		5950	18	63	...
Presspahn	*a*	6650	2%	1·61	4150	> 68	...	...
	b	> 9000			> 5600	> 68	About 130	...
	c	> 9000			> 5600	> 68	,, 200	...
Presspahn and Standard Varnish	*a*	3610	8% 12%	0·34	10500	26	...	...
	b	7120			21000	34	16	...
	c	9000			> 26000	30	25	...
	d	9000			> 26000	27	44	...
Manilla Paper	*a*	1540	8%	0·28	5500	28	...	...
	b	1540	2%		5500	11	13	...
	c	1590	5%		5700	9	25	...
Manilla Paper	*a*	1620	4%	0·38	4300	31	...	...
	b	1920	4%		5100	19	1·6	4
	c	1840	5%		4800	11	44	...

TABLE XLVI.—*continued.*

Substance.	Condition.	Disruptive Voltage.	Ratio of Max. Diff. from Mean to Mean.	Thickness mm.	Volts per mm.	Punching Pressure Kilogrammes.	Bending Test. Cylinder Diameter Millimeters.	Bending Test. Times without Breaking.
Manilla Paper and Standard Varnish	*a*	1800	2%	0·34	5300	25	...	...
	b	3400	8%		10000	21	25	...
	c	4340	8%		12700	19	51	...
	d	4180	9%		12300	17	63	...
Waterproof Board	*a*	2420	2%	0·29	8300	28	...	...
	b	3720	7%		12800	30	1·6	10
	c	3630	11%		12500	15	25·	...
Waterproof Board	*a*	3300	4%	0·44	7500	43	...	...
	b	4480	17%		10200	47	1·6	10
	c	5200	10%		11800	26	25·	...
Oiled Cloth	*a*	4580	4%	0·22	21000	13	...	...
	b	5110	20%		23000	12	6·3	...
	c	4650	14%		21000	11	16	...
	d	3940	12%		18000	9	25	...
Red Oiled Paper	*a*	6600	6%	0·25	26000	14	...	...
	b	6850	11%		27000	15	13	...
	c	7900	13%		31000	17	13	...
	d	6940	8%		28000	13	32	...
Black Oiled Board	*a*	5320	2%	0·30	17700	27	...	...
	b	5460	8%		15200	28	25	...
	c	6170	3%		20600	25	51	...
	d	4870	4%		16200	15	63	...

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